MR No. L5E04

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

ORIGINALLY ISSUED
May 1945 as
Memorandum Report L5E04

PERFORMANCE SELECTION CHARTS FOR GLIDERS AND TWIN-ENGINE TOW PLANES

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NACA

WASHINGTON

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MEMORANDUM REPORT

for the

Army Air Forces, Air Technical Service Command

PERFORMANCE SELECTION CHARTS FOR GLIDERS AND TWIN-ENGINE TOW PLANES

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SUMMARY

This report presents performance charts for gliders and twin-engine tow planes. Three sets of charts are presented showing the performance of gliders having different degrees of aerodynamic and structural refinement. For any glider, the charts show the gliding angle, the useful load, the stalling speeds, the power required for level flight at various speeds and the power required while climbing at various speeds.

The tow-plane charts show the performance which could be obtained from tow planes powered by two 2000-horsepower engines. The tow-plane charts present the stalling speeds, power required for level flight at various speeds, and the power required while climbing at various speeds. Charts also show the range for any combination of tow plane and gliders.

INTRODUCTION

This report presents charts which may be used to estimate the performance of any combination of glider and tow plane or they may be used to investigate the desirability of components to give some desired performance. The performance of a glider and tow-plane unit depends, not on the maximum efficiency of the components, but on their efficiencies when operated at the same speed. This means that a good glider and a good tow plane do not necessarily form a good unit. The two must be selected to operate efficiently at the same speeds. In actual development it may not be practical to produce the ideal glider or have available the appropriate tow plane to tow the glider. Combat conditions and the expendibility of military gliders may make it impossible to have on hand the optimum gliders for each mission. As the mission of the glider varies, it may be desirable to place different emphasis on the structural and aerodynamic efficiencies.

For this reason, three different sets of performance charts are presented having gradually increasing structural and aerodynamic efficiencies and typical load factors, aspect ratios, and wing thickness ratios. The first set of charts is based on structural and aerodynamic refinement approximately equal to that of existing military gliders. The second set is similar to new experimental designs being made at the present time. The aerodynamic cleanness is assumed to be better and the wing thickness ratio is increased in order to save structural weight by decreasing the amount of material needed for bending strength. For small gliders the minimum allowable thickness of structural material may make it impossible to increase the thickness ratio in order to save weight. Good finishes may be profitable only on gliders having high wing loadings. The third class consists of gliders having refinement approximately equal to the best obtained in powered airplanes. The structural efficiencies of these gliders are higher than those in the first two parts. They are well streamlined, have good finishes, and have retractable landing gears.

The set of tow-plane charts presents airplanes designed specifically for towing gliders. These tow planes have assumed structural and aerodynamic efficiencies similar to those of existing cargo airplanes. The tow planes presented are assumed to be designed for maximum range. In actual practice it may be desirable to substitute other loads for part of the fuel allowed for on the long-range tow planes. All the tow planes have been assumed to be twin-engine tow planes powered by two 2000-horsepower engines. The charts are prepared on coordinates of wing loading and power loading which allows their use on engines of other sizes for comparing trends.

For the sake of brevity, all the charts are for sea-level operation; however, the trends shown will be similar to those of altitude operation except that the speeds will be somewhat greater at higher altitudes.

PRESENTATION OF CHARTS

Charts are presented for three types of gliders and one type of tow plane. The gliders of type 1 (figs. 1(a) to 5(f)) have an aspect ratio of 8 and a 12-percent wing thickness ratio at the root chord. An aspect ratio of 9 and a 20-percent wing thickness ratio are used for the second type (figs. 6(a) to 10(f)). The gliders of type 3 (figs. 11(a) to 14(f)) have an aspect ratio of 10 and a 20-percent wing thickness ratio. The performance of the three types of gliders is presented on coordinates of gross weight and wing loading. The use of the same coordinates for all types of charts facilitates their superposition to form a composite chart showing the interrelationship of the useful loads and the various types of performance.

The tow planes are presented on charts having coordinates of power loading and wing loading. All the tow planes considered in this report have two 2000-horsepower engines mounted in wing nacelles. The power loading coordinate is the design gross weight divided by 4000. The tow-plane charts can be used with the glider charts to determine the performance of any combination of tow plane and gliders.

The method of analysis is presented in the appendices. A list of figures is given immediately preceding figure 1(a). Examples of the use of the charts are given here.

USE OF CHARTS

Selection of gliders

Problem: Select glider A of type 1 to carry 6000 pounds and have a stalling speed of 40 miles per hour with flaps.

From figure 3(a) read a wing loading of 8.2 on the 40-mile-per-hour curve.

From figure 1(a) read a gross weight of 14,750 pounds where W/S of 8.2 intersects 6000 pounds useful load.

The performance of the glider may be determined by the use of figures 1(a) to 5(f).

Maximum glide ratio	Speed at L/D_{max} (mph)	Stalling speed with flaps (mph)	Stalling speed without flaps (mph)	Power required at 120 mph level (thp)	Power required to climb 500 ft/min at 120 mph (thp)
13 to 1	64	40	48	685	880

Selection of tow planes

If the power required by the gliders coincides with one of the values used in preparing the charts, a tow plane may be selected for a certain range directly from the charts presented. When the power required by the gliders does not coincide with one of the values used in preparing the charts, the appropriate tow plane may be selected after the towing speed and wing loading are determined. For that speed and wing loading, constant-range curves may be plotted on coordinates of power loading versus glider power required. By cross- plotting, range and glider power required may be used as coordinates to draw constant-power-loading curves from which gross weights may be obtained.

Selection of glider-tow plane combination

The tow planes must have wing loadings not much higher than those of the gliders they tow if they are to operate efficiently at the best speed for the gliders.

Problem: Select a tow plane capable of towing two gliders similar to glider A for 1000 miles at 120 miles per hour, releasing the gliders, and returning. The stalling speed of the tow plane is to be 50 miles per hour with flaps.

From figure 15(a) the wing loading will be 12.8. By plotting power loading versus glider power required for a wing loading of 12.8, a speed of 120 miles per hour, and a range of 2000 miles, a power loading of 10.4 is determined.

The gross weight of the tow plane will then be

$$W = 10.4 \times 4000$$
$$= 41,600 \text{ pounds}$$

and the wing area is

$$S = \frac{41,600}{12.8}$$
$$= 3250 \text{ square feet}$$

The wing area is very large for an airplane of this gross weight, being about double the wing area of the B-29.

From figure 24(a) the fuel load in the fuselage is 9800 pounds of which 5000 pounds may be carried in the wing.

Figure 22(d) shows power required by the tow plane in level flight is 680 thrust horsepower. The total thrust horsepower required by the tow plane and two gliders is

$$680 + 2(685) = 2045$$

For a propeller efficiency of 0.8 in level flight the brake horsepower required is

$$\frac{2045}{0.8} = 2555 \text{ brake horsepower}$$

Figure 23(d) shows power required by the tow plane climbing 500 feet per minute is 1300 thrust horsepower. The power required for each glider to climb 500 feet per minute at 120 miles per hour was previously found to be 880 thrust horsepower. The total brake horsepower based on a propeller efficiency of 0.75 for climbing is

$$\frac{1300 + 2(880)}{0.75} = 4080 \text{ brake horsepower}$$

This condition of flight is impossible since the maximum military rating of each engine is 2000 brake horsepower. This means that this combination of tow plane and gliders is not capable of climbing 500 feet per minute.

PERFORMANCE TRENDS

Effect of wing loading

Problem: Select two gliders of type 1 (figs. 1(a) to 5(f)) each of which is capable of carrying a 4600-pound useful load. Glider B is to have a stalling speed of 30 miles per hour with flaps and glider C is to have a stalling speed of 40 miles per hour. The two gliders are compared in the following table:

Glider	Gross weight (lb)	Wing loading (lb/sq ft)	Stalling speed with flaps (mph)	Percent useful load
B	13,700	4.6	30	33.6
C	10,200	8.2	40	45.0

The example shows that the selection of low stalling speeds decreases the percent useful load necessitating the design of heavier gliders to carry the same load. In this example the selection of a stalling speed of 30 miles per hour instead of 40 miles per hour has increased the weight of the glider by 3500 pounds, largely because of increased wing weight associated with a larger wing. This result suggests that means must be taken to keep the wing weights lower particularly on large gliders. This can be accomplished by increasing the thickness ratio and decreasing the aspect ratio. In small gliders it may not be possible to save weight by increasing the thickness ratio because of the minimum allowable thickness of some structural components. Even with reduced structural weights, large gliders must be designed with higher wing loadings than smaller gliders for the same percent useful load.

If low wing loadings are necessary, it may be desirable to build two small gliders, each carrying half the load, instead of one large glider. The total gross weight of the two gliders is nearly always less than that of one large glider but at high towing speeds the small gliders may require slightly more power.

The maximum glide ratio for glider C previously discussed is relatively low, 12.7 at 63.5 miles per hour. The fact that normal towing speeds are much higher than the speed for maximum L/D indicates the operational L/D of the glider will be much less than 12.7. At speeds higher than that for maximum L/D the profile drag is more important than induced drag. Consequently, a large improvement in performance can be obtained by designing gliders with less profile drag. This increased performance is seen in comparing the gliders of type 1 with those of type 2 and type 3 where the profile drag was reduced.

Comparison of the three types of gliders

Problem: Select gliders to carry 8000 pounds and have a stalling speed of 50 miles per hour with flaps. Glider D will be of type 1, glider E of type 2, and glider F of type 3.

Figures 3(a) and/or 8(a) show that each glider will have a wing loading of 12.8.

The performances of the three types are shown in the following tables:

Glider	Gross weight (lb)	Percent useful load	Wing loading (lb/sq ft)	Stalling speeds with flaps (mph)	Stalling speeds without flaps (mph)	Maximum glide ratio
D	18,500	43	12.8	50	60	12.3 to 1
E	15,200	53	12.8	50	60	13.9 to 1
F	15,700	51	12.8	50	60	19.2 to 1

Glider	Speed at L/D_{max}	Power required at 140 mph level (thp)	Power required climbing 500 ft/min at 140 mph (thp)	$\frac{\text{lb miles}}{\text{hp-hr}}$ at L/D_{max}	$\frac{\text{lb miles}}{\text{hp-hr}}$ at 140 mph
D	78	990	1270	1980	1130
E	78	710	940	2710	1580
F	87.5	450	685	3680	2480

The power required in level flight is very low for the type 3 gliders; therefore, the additional power required for climbing becomes a larger proportion of the total power required. The power required in level flight alone may not determine the practicability of towing the given glider.

For a more detailed comparison of the three types of gliders it may prove helpful to prepare charts such as figure 25 which shows the effect of wing loading on gliders with constant useful loads. Eight-thousand-pound useful loads were used in preparing this chart.

Effect of glider performance on tow-plane performance

Problem: Select tow planes for gliders D, E, and F capable of towing a glider for 1000 miles at 140 miles per hour, releasing the glider and returning. The stalling speeds of the tow planes are to be 50 miles per hour with flaps.

The wing loading will be 12.8 for each plane. By plotting power loading versus glider power required for a wing loading of 12.8, a speed of 140 miles per hour, and a range of 2000 miles, power loadings can be determined as explained in a previous example.

The performance of the tow planes are shown in the following tables:

Gliders		Tow planes				
Type	Useful load of glider (lb)	Power loading (lb/bhp)	Gross weight (lb)	Wing loading (lb/sq ft)	Stalling speed with flaps (mph)	Fuel load (lb)
D	8000	10.4	41,600	12.8	50	11,600
E	8000	8.7	33,600	12.8	50	8,000
F	8000	7.95	31,800	12.8	50	6,200

Combinations of tow planes and gliders				
Type	Power required by tow plane in level flight at 140 mph (thp)	Power required by tow plane climbing 500 ft/min at 140 mph (thp)	Power required by combination in level flight at 140 mph (bhp)	Power required by combination climbing 500 ft/min at 140 mph (bhp)
D	920	1570	2390	3790
E	775	1300	1860	2990
F	710	1200	1450	2510

With type 3 gliders particularly, the weight of the gliders that can be towed may be much more than the weight of a short-range tow plane. This may make it impossible to use snatch take-offs in launching the gliders. It may be necessary to build heavier tow planes and let them carry part of the load.

CONCLUDING REMARKS

A study of the charts of the report brings out these conclusions:

1. Gliders of type 1, representing existing military gliders, have high structural weights. Because of high wing weights, it is usual practice to design heavy gliders for higher wing loadings than small gliders in order to keep a high percentage of useful load.

2. The assumption of thicker wings for the gliders of type 2 decreased the structural weights,hence,giving better useful loads for large gliders not having their structural weights determined by minimum allowable material thickness.

3. The gliders of type 3, having high aerodynamic and structural efficiencies, require much less power for carrying a given load in level flight than the gliders of types 1 and 2. For these gliders the additional power required to climb is a much larger proportion of the total power required than formerly. The total weight of the gliders that can be towed in steady flight

is so high that some other requirement such as take-off may determine the actual loads that can be carried.

4. In some cases, particularly with gliders having low wing loadings or low towing speeds, it may be advantageous to use two small gliders, each carrying half the load rather than one large glider. The total gross weight of the two gliders is nearly always less than that of the one large glider, but at high speeds the small gliders may require slightly more power.

5. Tow planes need to have wing loadings not much higher than those of the gliders in order that they will not stall but will operate efficiently when operated at the best speed for the gliders.

6. Short-range tow planes are fairly light as compared to the weight of the gliders they are capable of towing. This condition may not be desirable for "snatch take-offs." It may be advantageous to build larger, heavier tow planes and let them carry part of the cargo or to use some other method of launching the gliders.

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APPENDIX A

SYMBOLS

The symbols used are defined as follows:

C_1	weight-distribution factor
C_{D_o}	profile-drag coefficient
F	projected frontal area, sq ft
f	ultimate load factor
K	structural efficiency factor
L/D	lift to drag ratio
R	aspect ratio
S	wing area, sq ft
t	thickness to chord ratio
thp	thrust horsepower
W	gross weight, lb
W_1	wing weight, lb
W_2	distributed load, lb
W_e	weight of electrical system, lb
W_f	weight of fuel, lb
W_{fe}	weight of fixed equipment, lb
W_h	weight of hydraulic equipment, lb
W_u	useful load, lb

METHOD OF ANALYSIS FOR GLIDERS OF TYPE 1

The equations used for the gliders of type 1 are based on an analysis of about ten existing military gliders. The performances shown herein are obtainable from gliders designed and produced by present methods.

DRAG

The wing drag coefficient is taken as 0.018; the tail-drag coefficient based on wing area is taken as 0.005; the fuselage-drag coefficient, based on the frontal area, is 0.25. The complete profile-drag equation based on wing area is

$$C_{D_o} = 0.018 + 0.005 + 0.25 \frac{F}{S}$$

The fuselage frontal area is assumed to vary as the two-thirds power of the useful load

$$F = 0.15 \, W_u^{2/3}$$

These drag coefficients and frontal areas check values obtained from analysis of existing gliders.

WING THICKNESS

A 12-percent wing thickness ratio at the root chord was used for all gliders of type 1.

ULTIMATE LOAD FACTOR

An ultimate load factor of 4.5 was used for all gliders.

ASPECT RATIO AND SPAN EFFICIENCY FACTOR

An aspect ratio of 8 was used for all gliders of type 1. The span efficiency factor was taken as 0.8. The induced-drag coefficient is then

$$C_{D_i} = \frac{C_L^2}{0.8\pi 8}$$

WEIGHTS

Based on Air Force gliders, the following assumptions were made:

1. Fuselage weight is 17 percent of glider gross weight.
2. Tail weight is 17 percent of the wing weight.
3. Weight of fixed equipment is 30 + 0.045 W.

WING WEIGHT

In keeping with the methods used in reference 1 the wing weight was calculated as

$$W_1 = \frac{W}{\dfrac{Kt}{fR^{3/2}S^{1/2}} + 1}$$

This equation assumes wing weight to be proportional to the structural weight required for strength in bending. K was determined to be 75,000 based on existing gliders.

Combining all of these weight factors, the following equation for the empty weight of the glider was obtained.

$$W_{empty} = 1.17\left(\frac{W}{\dfrac{Kt}{fR^{3/2}S^{1/2}} + 1}\right) + 0.17\ W + W_{fe}$$

APPENDIX B

METHOD OF ANALYSIS FOR GLIDERS OF TYPE 2

The equations used for the gliders of type 2 are based on an analysis of recent military designs and the performances shown should be obtainable by present production methods.

DRAG

The wing-drag coefficient is taken as 0.015; the tail-drag coefficient based on wing area is taken as 0.004; the fuselage drag coefficient based on the frontal area is 0.20. The complete profile-drag equation based on wing area is

$$C_{D_o} = 0.015 + 0.004 + 0.20 \frac{F}{S}$$

The drag of the type 2 glider is estimated from the analysis of recent designs which represent an improvement over earlier designs.

The fuselage frontal area is assumed to vary as the two-thirds power of the useful load.

$$F = 0.15 \, W_u^{2/3}$$

WING THICKNESS

A 20-percent wing thickness ratio at the root chord was used for all gliders of type 2.

ULTIMATE LOAD FACTOR

An ultimate load factor of 4.5 was used for all gliders.

ASPECT RATIO AND SPAN EFFICIENCY FACTOR

An aspect ratio of 9 was used for all gliders of type 2. The span efficiency factor was taken as 0.8. The induced-drag coefficient is then

$$C_{D_i} = \frac{C_L^2}{0.8\pi 9}$$

WEIGHTS

The following assumptions were made based on Air Force gliders:

1. Fuselage weight is 17 percent of glider gross weight.

2. Tail weight is 17 percent of the wing weight.

3. Weight of fixed equipment is 30 + 0.045 W.

WING WEIGHT

In keeping with the methods used in reference 1 the wing weight was calculated as

$$W_1 = \frac{W}{\frac{Kt}{fR^{3/2}S^{1/2}} + 1}$$

K was determined to be 75,000 based on existing gliders.

The complete equation for the empty weight of the glider is

$$W_{empty} = 1.17\left(\frac{W}{\frac{Kt}{fR^{3/2}S^{1/2}} + 1}\right) + 0.17\ W + W_{fe}$$

APPENDIX C

METHOD OF ANALYSIS FOR GLIDERS OF TYPE 3

The equations used for the gliders of type 3 give performances which could be obtained by gliders having the aerodynamic and structural refinement of the best existing powered airplanes.

DRAG

The wing drag coefficient is taken as 0.009; tail drag coefficient based on wing area is taken as 0.003; the fuselage drag coefficient based on the frontal area is 0.10. The complete profile-drag equation based on wing area is:

$$C_{D_o} = 0.009 + 0.003 + 0.10\,\frac{F}{S}$$

The drags of type 3 gliders are similar to those of approximately 25 all-metal airplanes which were investigated.

The fuselage frontal area is assumed to vary as the two-thirds power of the useful load.

$$F = 0.15\,W_u^{2/3}$$

WING THICKNESS

A 20-percent wing thickness ratio at the root chord was used for all gliders of type 3.

ULTIMATE LOAD FACTOR

An ultimate load factor of 4.5 was used for gliders.

ASPECT RATIO AND SPAN EFFICIENCY FACTOR

An aspect ratio of 10 was used for all gliders of type 3. The span efficiency factor was taken as 0.8. The induced-drag coefficient is then

$$C_{D_i} = \frac{C_L^2}{0.8\pi 10}$$

WEIGHTS

The following assumptions were made based on Air Force gliders.

1. Fuselage weight is 14 percent of glider gross weight.

2. Tail weight is 15 percent of the wing weight.

3. Weight of fixed equipment is 30 + 0.045 W.

4. Landing-gear weight is 8 percent of gross weight.

WING WEIGHT

In keeping with the methods used in reference 1 the wing weight was calculated as

$$W_1 = \frac{W}{\frac{Kt}{fR^{3/2}S^{1/2}} + 1}$$

K was assumed to be 100,000.

The complete equation for the empty weight of the glider is

$$W_{empty} = 1.15\left(\frac{W}{\frac{Kt}{fR^{3/2}S^{1/2}} + 1}\right) + 0.08\ W + 0.14\ W + W_{fe}$$

APPENDIX D

METHOD OF ANALYSIS FOR TOW PLANES

The equations used for tow planes are based on an analysis of existing cargo planes. The predicted performances should be obtainable by present production methods.

DRAG

The wing drag coefficient is taken as 0.009; the tail drag coefficient based on wing area is taken as 0.002; the fuselage drag coefficient, based on the frontal area, is 0.10. The complete profile-drag equation based on wing area is

$$C_{D_o} = 0.009 + 0.002 + 0.10 \frac{F}{S}$$

The frontal area is

$$F = 30 + 0.032 \, W_f^{2/3}$$

where 30 is the frontal area of the nacelles and a minimum size fuselage.

WING THICKNESS

A 15-percent wing thickness ratio at the root chord was used for all tow planes.

ULTIMATE LOAD FACTOR

An ultimate load factor of 4.5 was used for all tow planes.

ASPECT RATIO AND SPAN EFFICIENCY FACTOR

An aspect ratio of 8 was used throughout the calculations. The span efficiency was taken as 0.9. The induced-drag coefficient is then

$$C_{D_i} = \frac{C_L^2}{0.9\pi 8}$$

PROPELLER EFFICIENCY

For level flight a propeller efficiency of 85 percent is assumed to be attained. To simplify the calculations the cooling power was assumed to be 5 percent of the brake horsepower. This gives an effective efficiency of 80 percent. In climb the effective efficiency is 75 percent.

WEIGHTS

Based on existing cargo planes, the following assumptions were made:

1. Fuselage weight is 9 percent of the gross weight.
2. Tail weight is 14 percent of the wing weight.
3. Landing gear is $6\frac{1}{2}$ percent of the gross weight.
4. Weight of the fixed equipment is $2\frac{1}{2}$ percent of the gross weight plus the weight of the hydraulic and electrical systems. The weight of the electrical system is taken as 90 + 0.009 W. The weight of the hydraulic system is taken as 140 where W is less than 26,000 and 140 + 0.038 (W - 26,000) where W is greater than 26,000.

5. Since two 2000-horsepower engines are used in all tow planes, it is assumed that the weight of the nacelle and power plant groups is 8000 pounds in every case.

In keeping with the methods used in reference 1 the wing weight was calculated as

$$W_1 = \frac{W - C_1(W_2)}{\frac{Kt}{fR^{3/2}S^{1/2}} + 1}$$

K was determined to be 100,000 based on existing cargo planes. C_1, the weight-distribution factor, was taken as 0.85.

W_2, the distributed load in the wing, includes 8000 pounds for the nacelle and power-plant groups and 5000 pounds of fuel or other load to be carried in the wing.

The useful load to be carried in the fuselage is the gross weight minus the empty weight. Allowing 400 pounds for a two-man crew, the weight of fuel which can be carried in the fuselage is assumed to be $0.85(W_u - 400)$ where W_u is the useful load in the fuselage.

Combining all these weight factors we obtain the following equation for the empty weight of the tow plane:

$$W_{empty} = 1.14\left(\frac{W - C_1(W_2)}{\frac{Kt}{fR^{3/2}S^{1/2}} + 1}\right) + 0.18\,W + W_e + W_h + 8000$$

REFERENCE

1. Brevoort, Maurice J., Stickle, George W., and Hill, Paul R.: Generalized Selection Charts for Bombers Powered by Two, Four, and Six 3000-Horsepower Engines. NACA MR, Aug. 13, 1942.

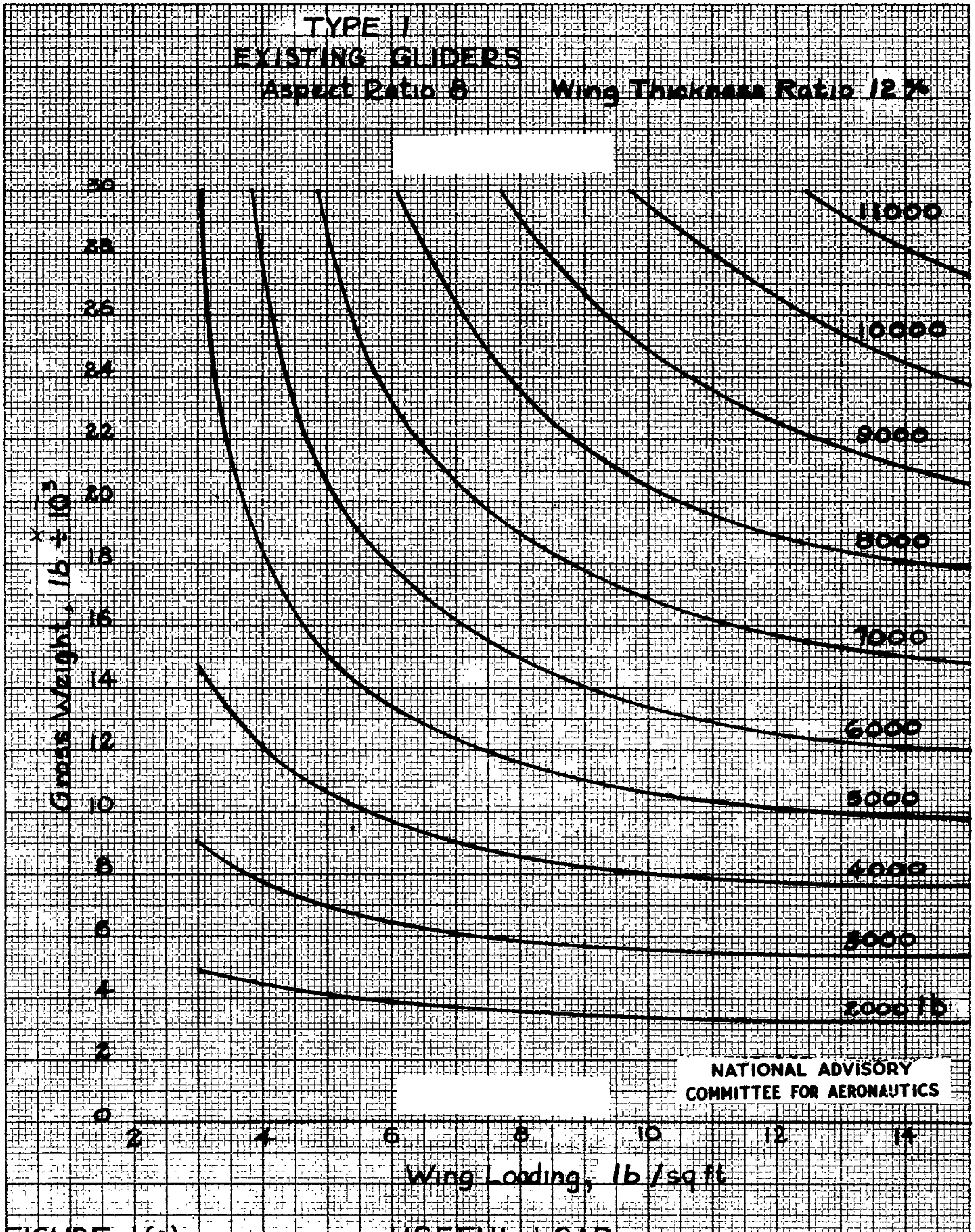

FIGURE 1(a) USEFUL LOAD

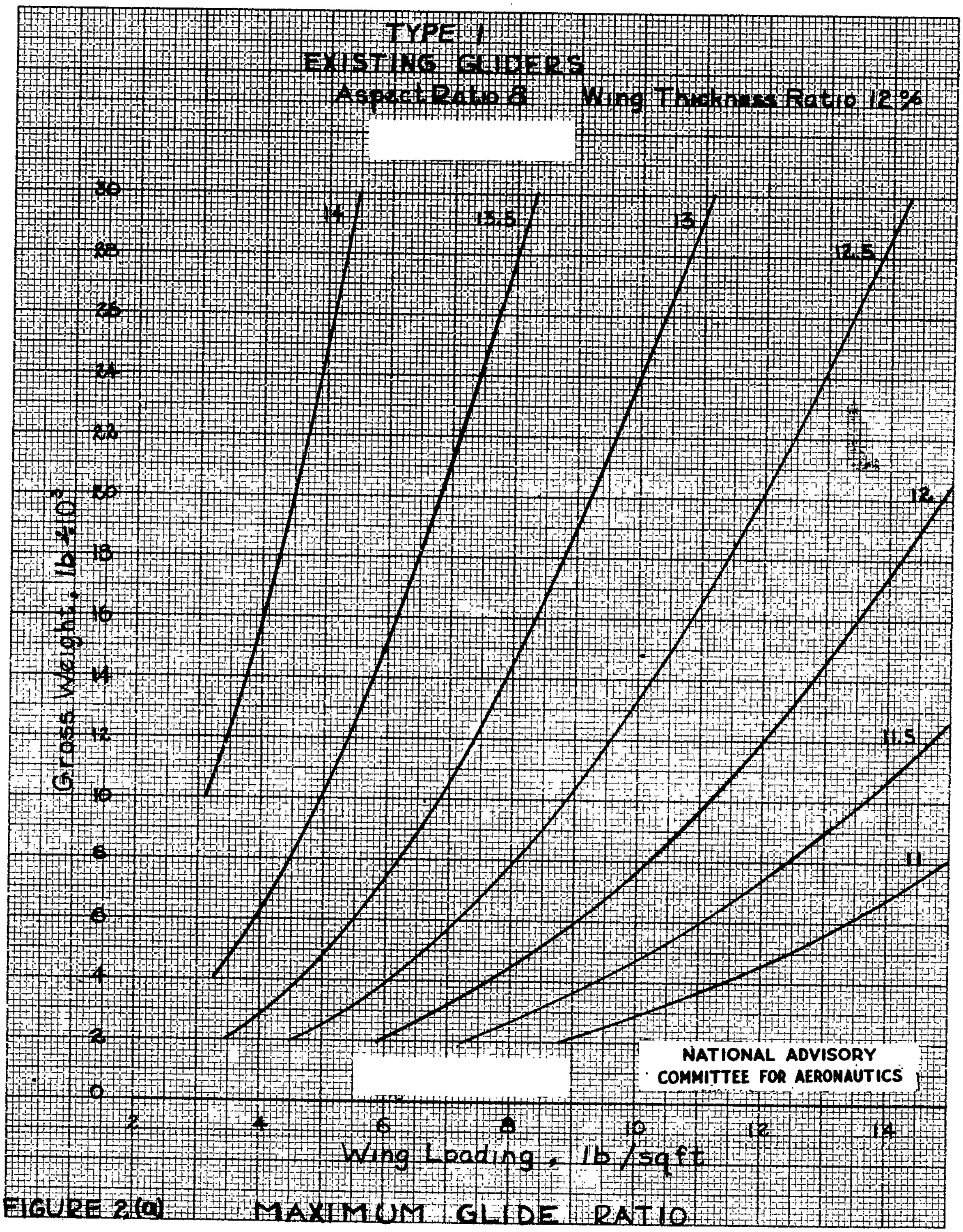

FIGURE 2(a) MAXIMUM GLIDE RATIO

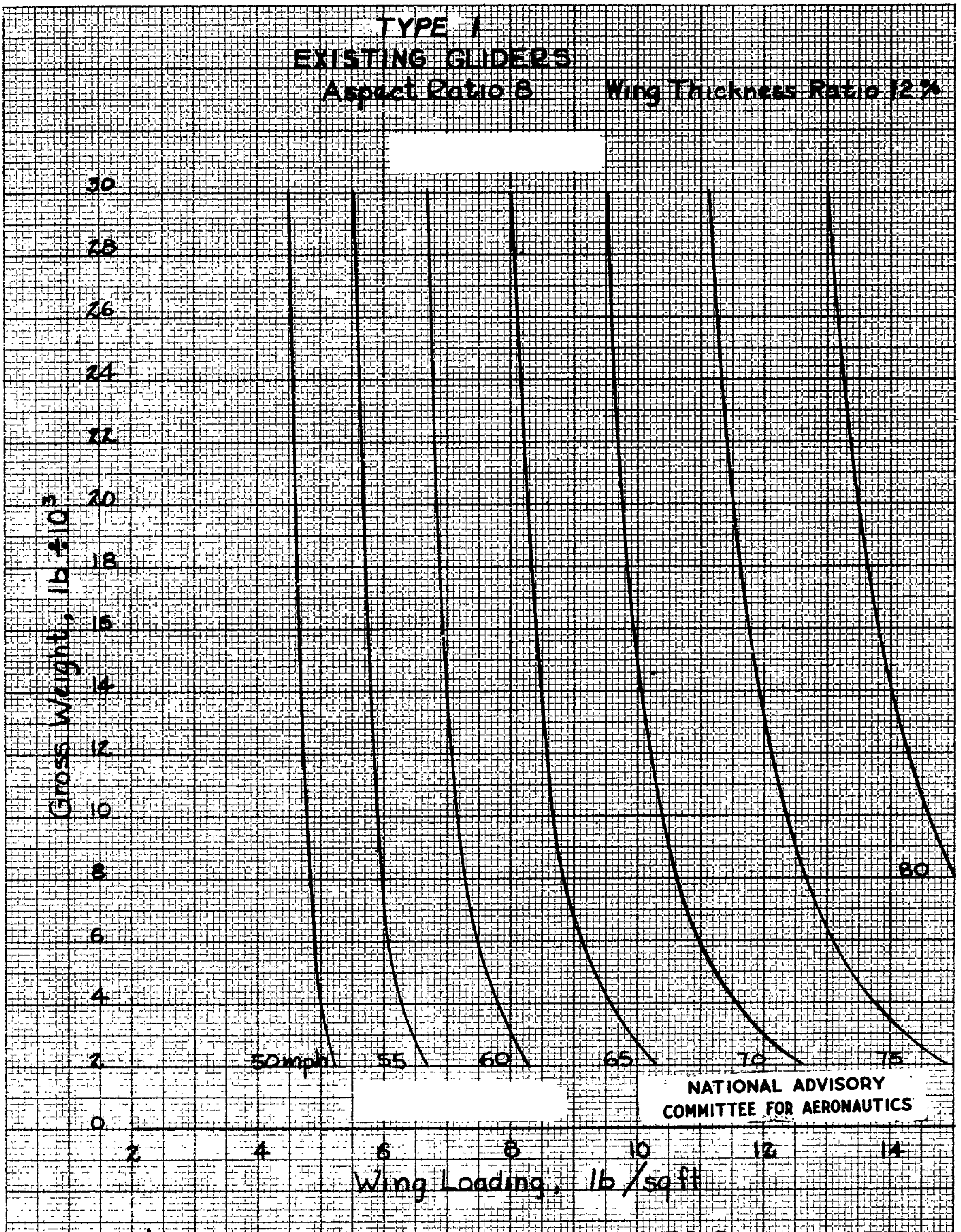

FIGURE 2(b) SPEEDS AT MAXIMUM LIFT TO DRAG RATIO

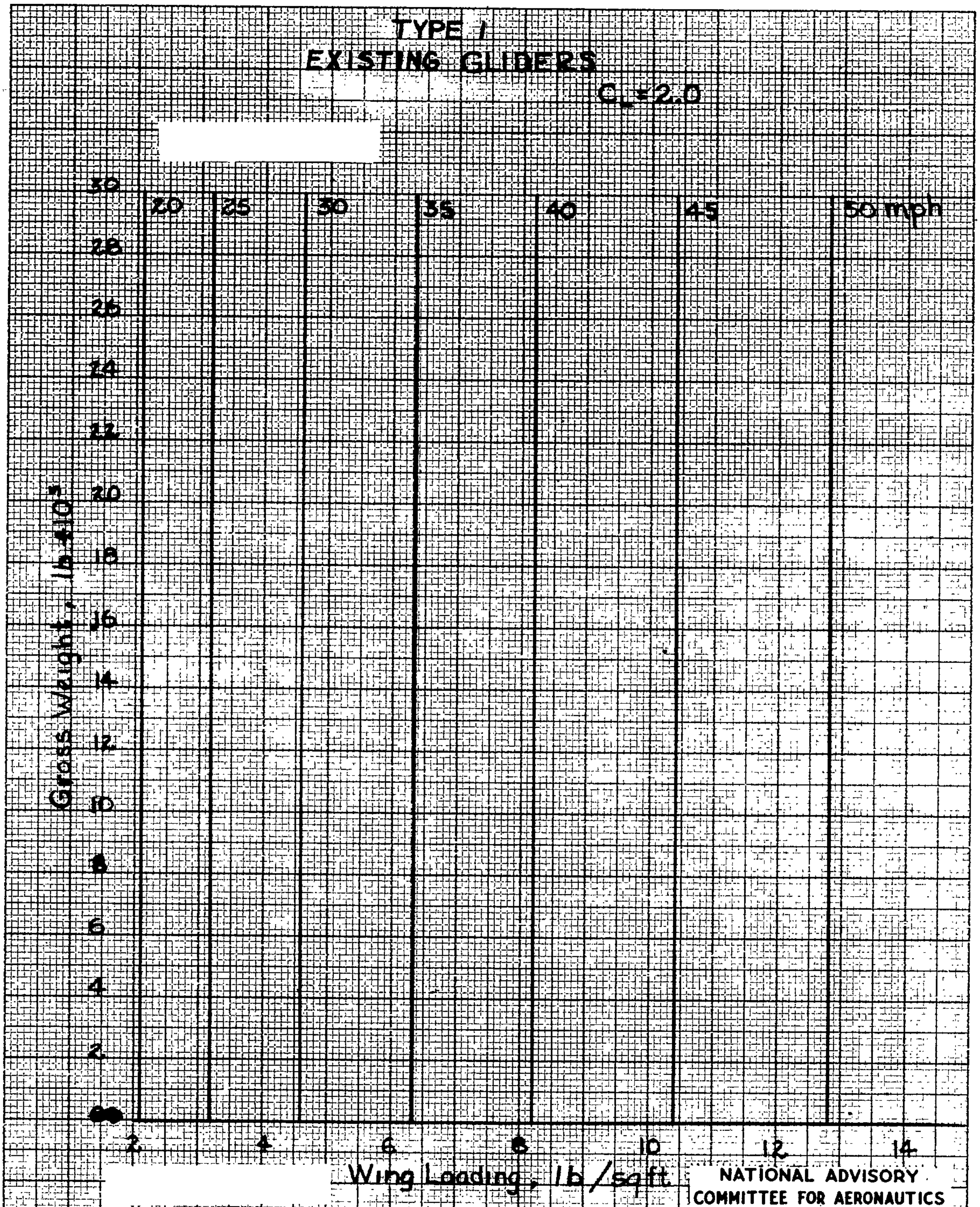

FIGURE 3 (a) STALLING SPEEDS WITH FLAPS

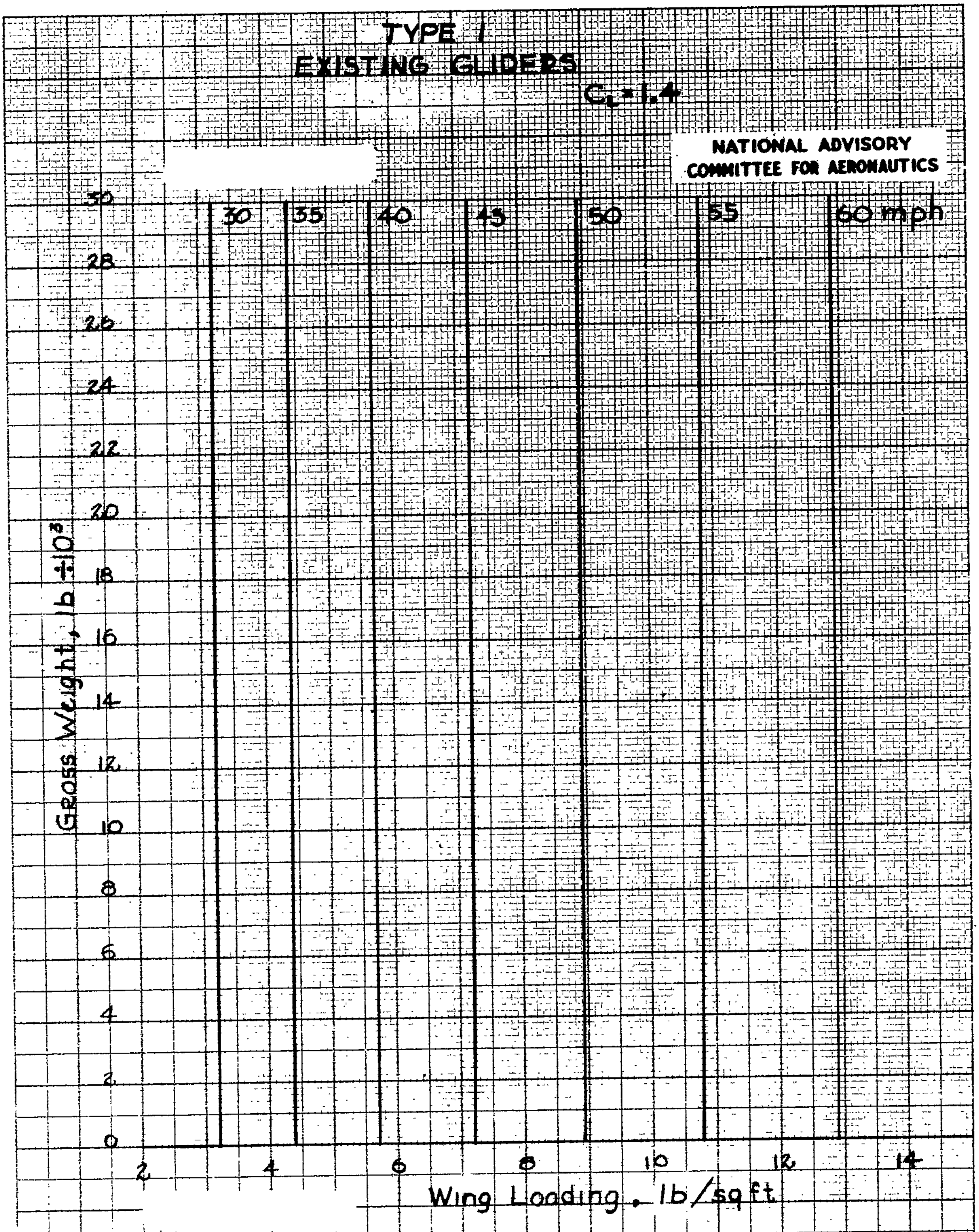

FIGURE 3 (b) STALLING SPEEDS WITHOUT FLAPS

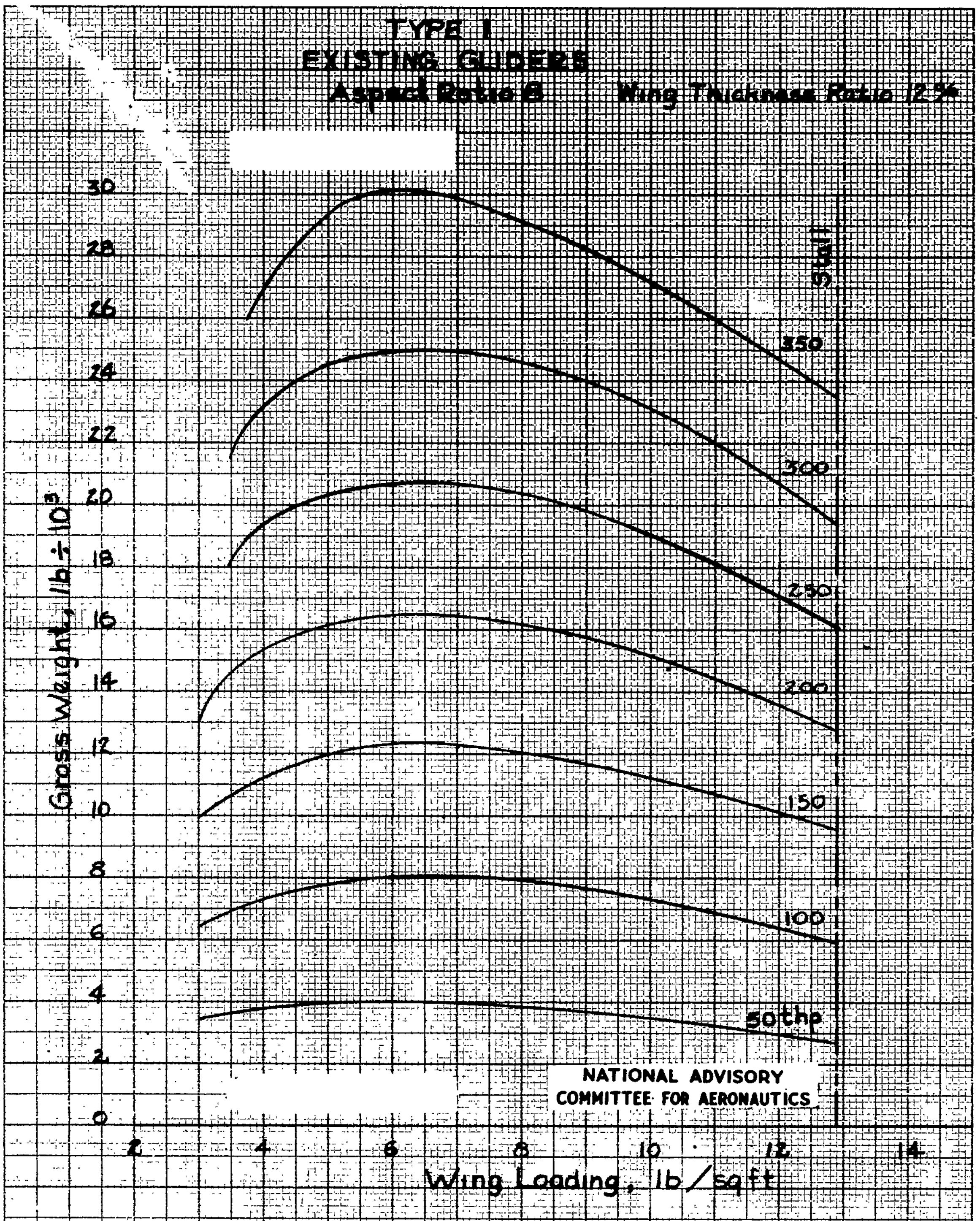

FIGURE 4(a) POWER REQUIRED AT 60 MPH LEVEL

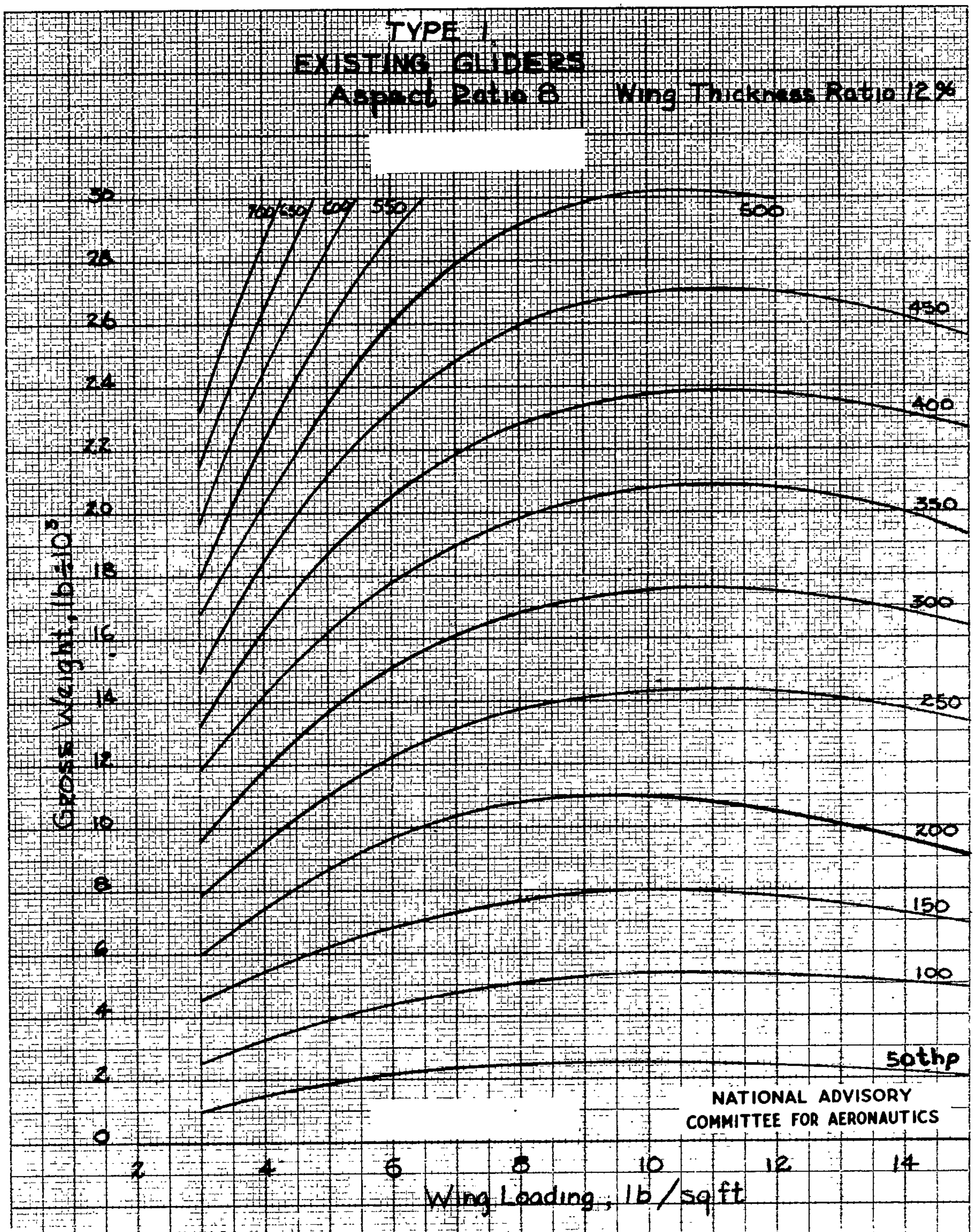

FIGURE 4(b) POWER REQUIRED AT 80 MPH LEVEL

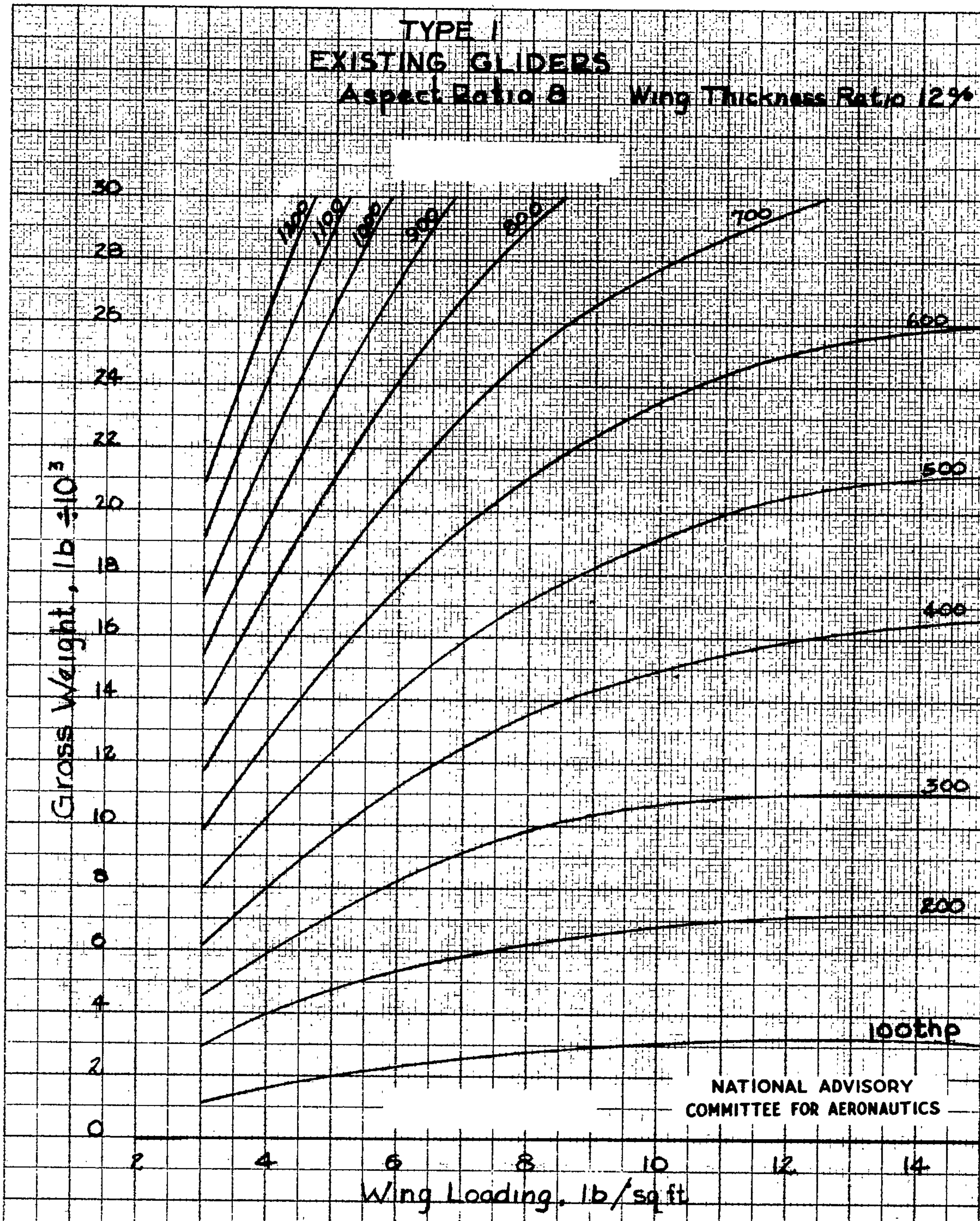

FIGURE 4(c) POWER REQUIRED AT 100 MPH LEVEL

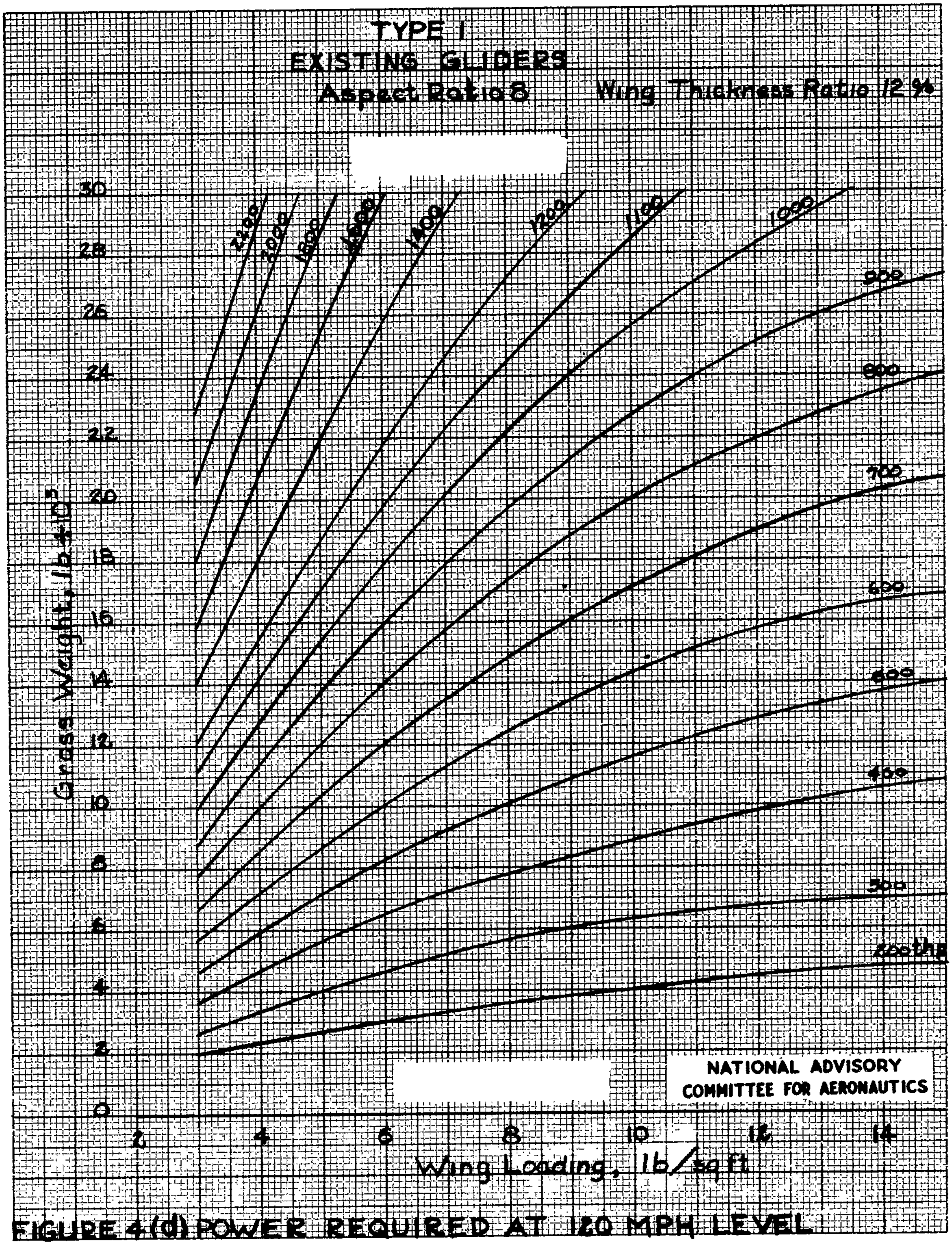

FIGURE 4(d) POWER REQUIRED AT 120 MPH LEVEL

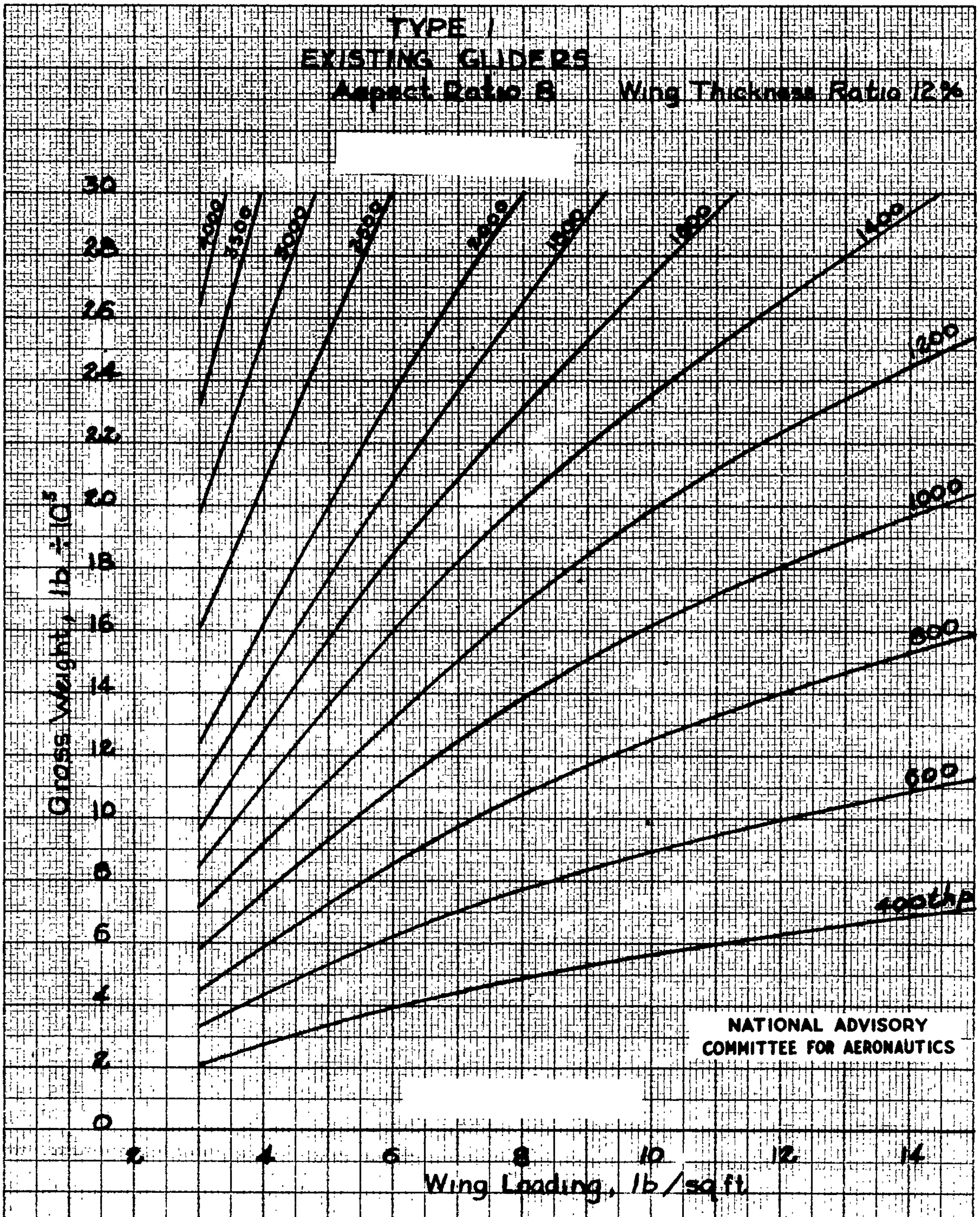

FIGURE 4(c) POWER REQUIRED AT 140 MPH LEVEL

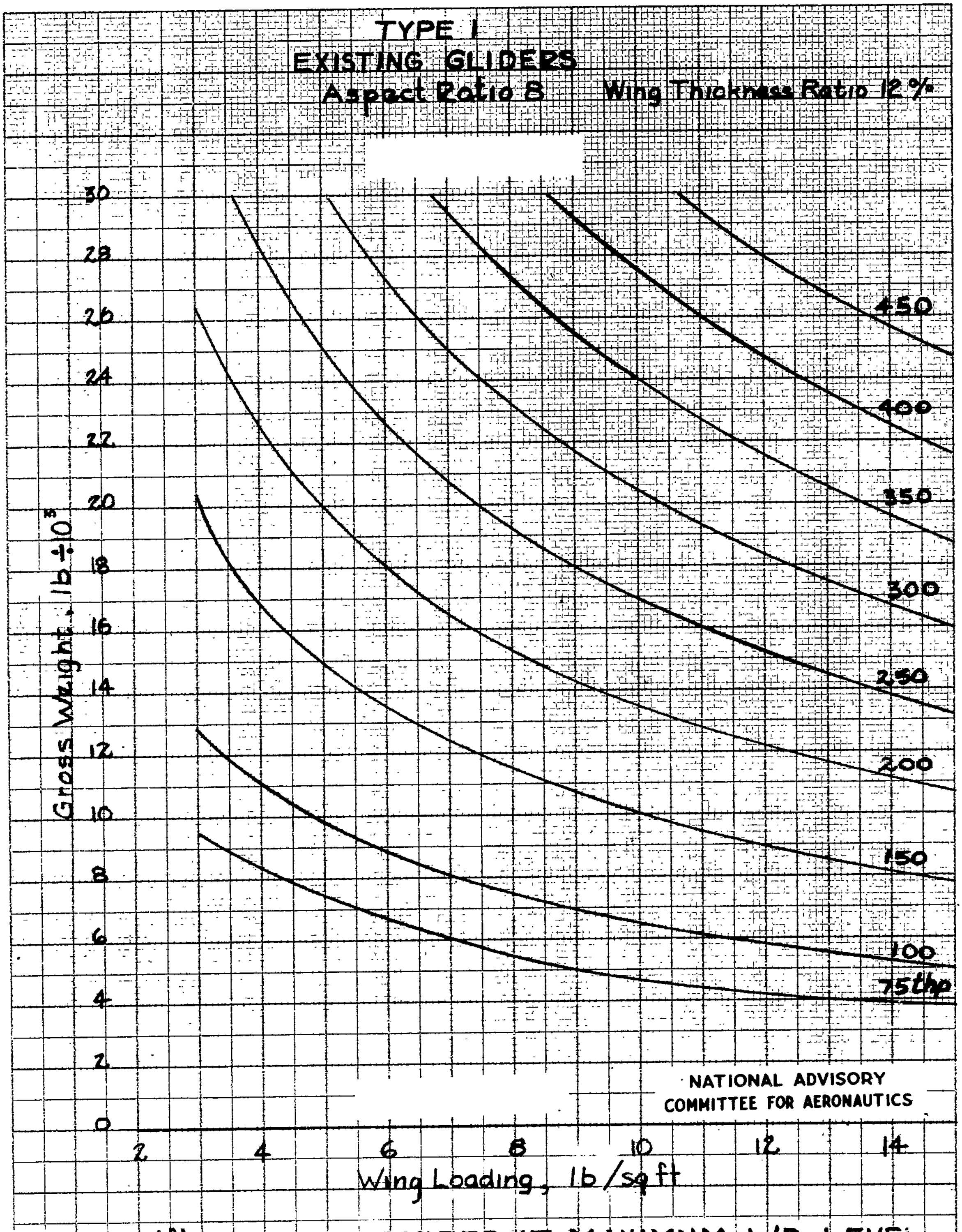

FIGURE 4(f) POWER REQUIRED AT MAXIMUM L/D LEVEL

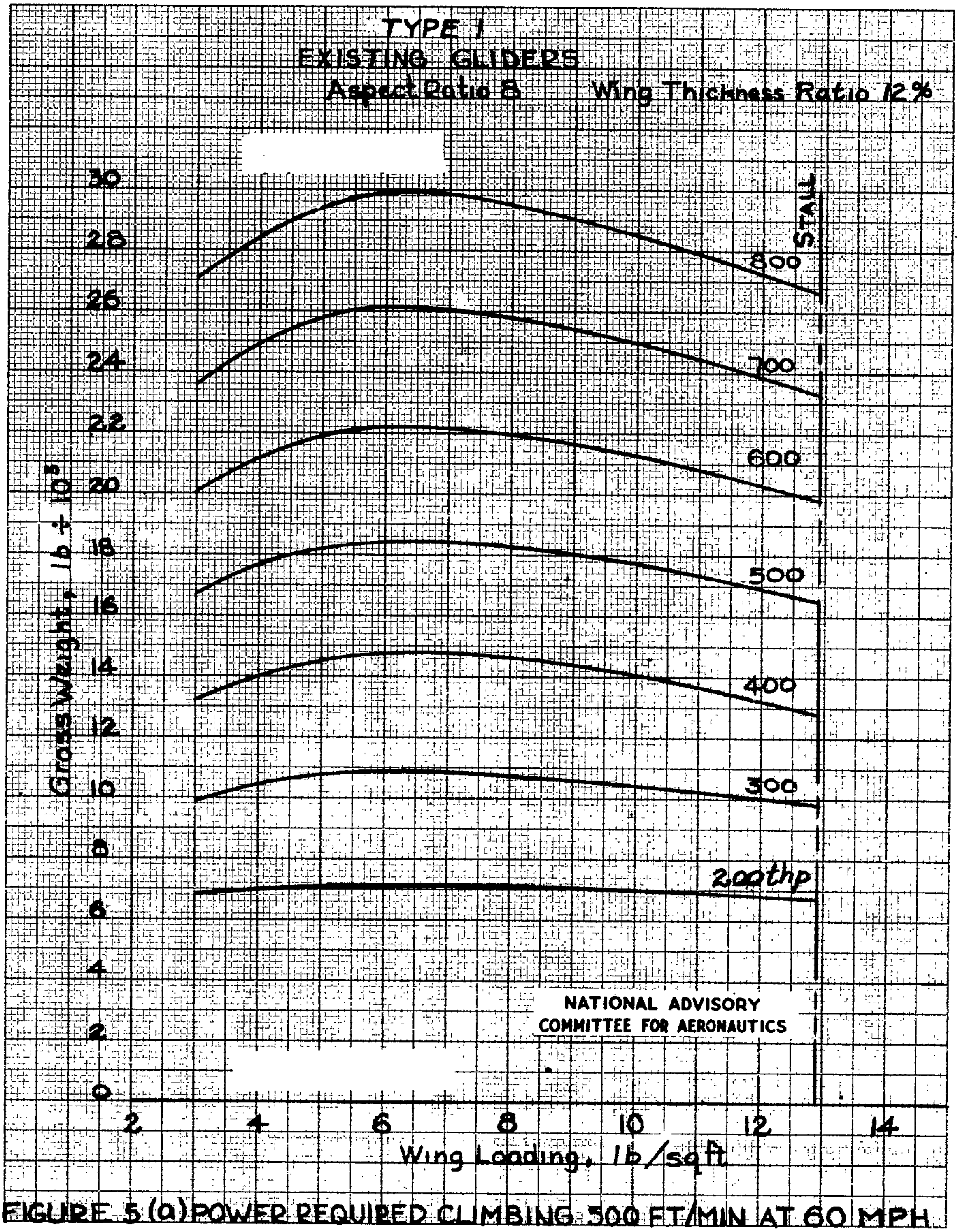

FIGURE 5 (a) POWER REQUIRED CLIMBING 500 FT/MIN AT 60 MPH

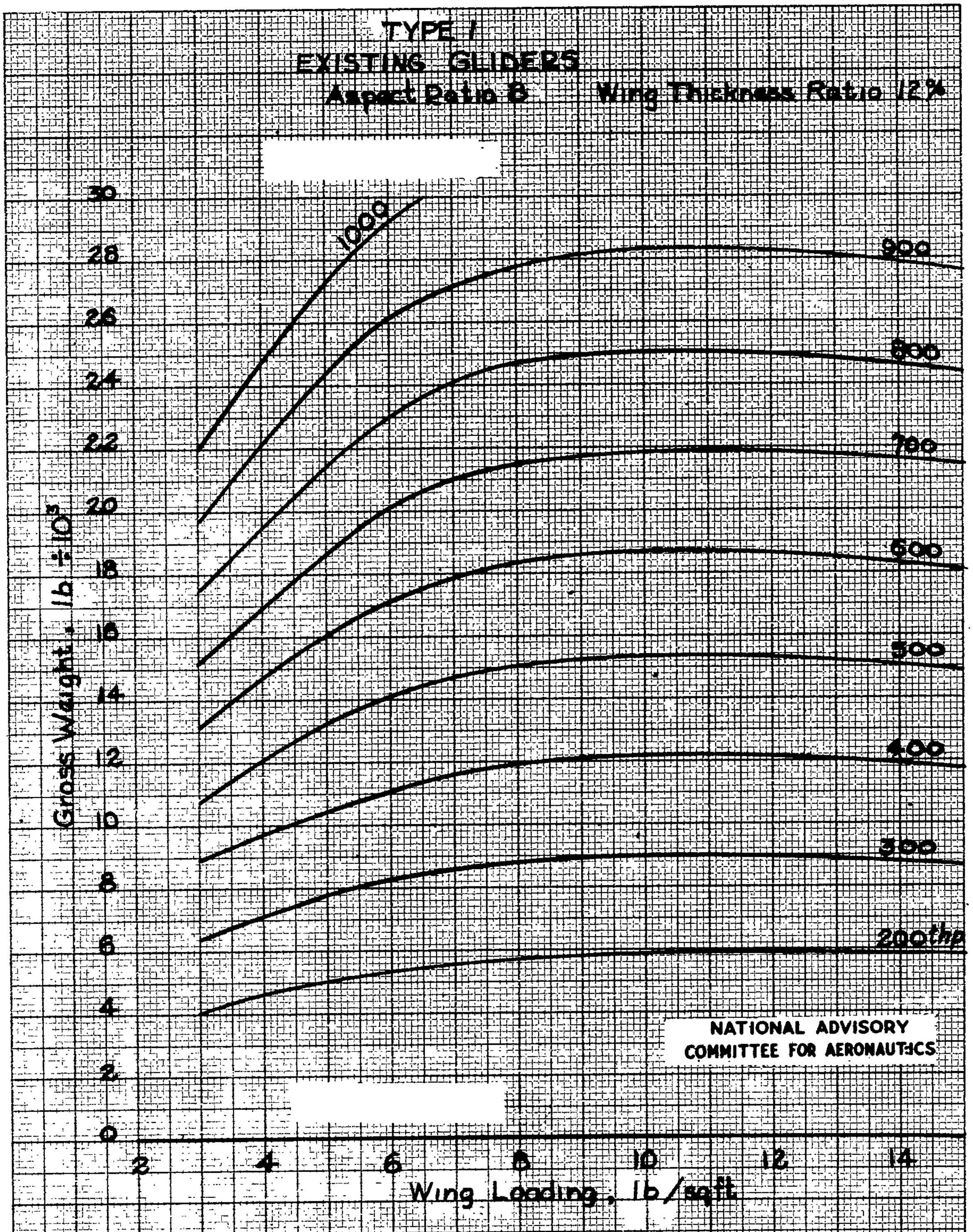

FIGURE 5(b) POWER REQUIRED CLIMBING 500 FT/MIN AT 80 MPH

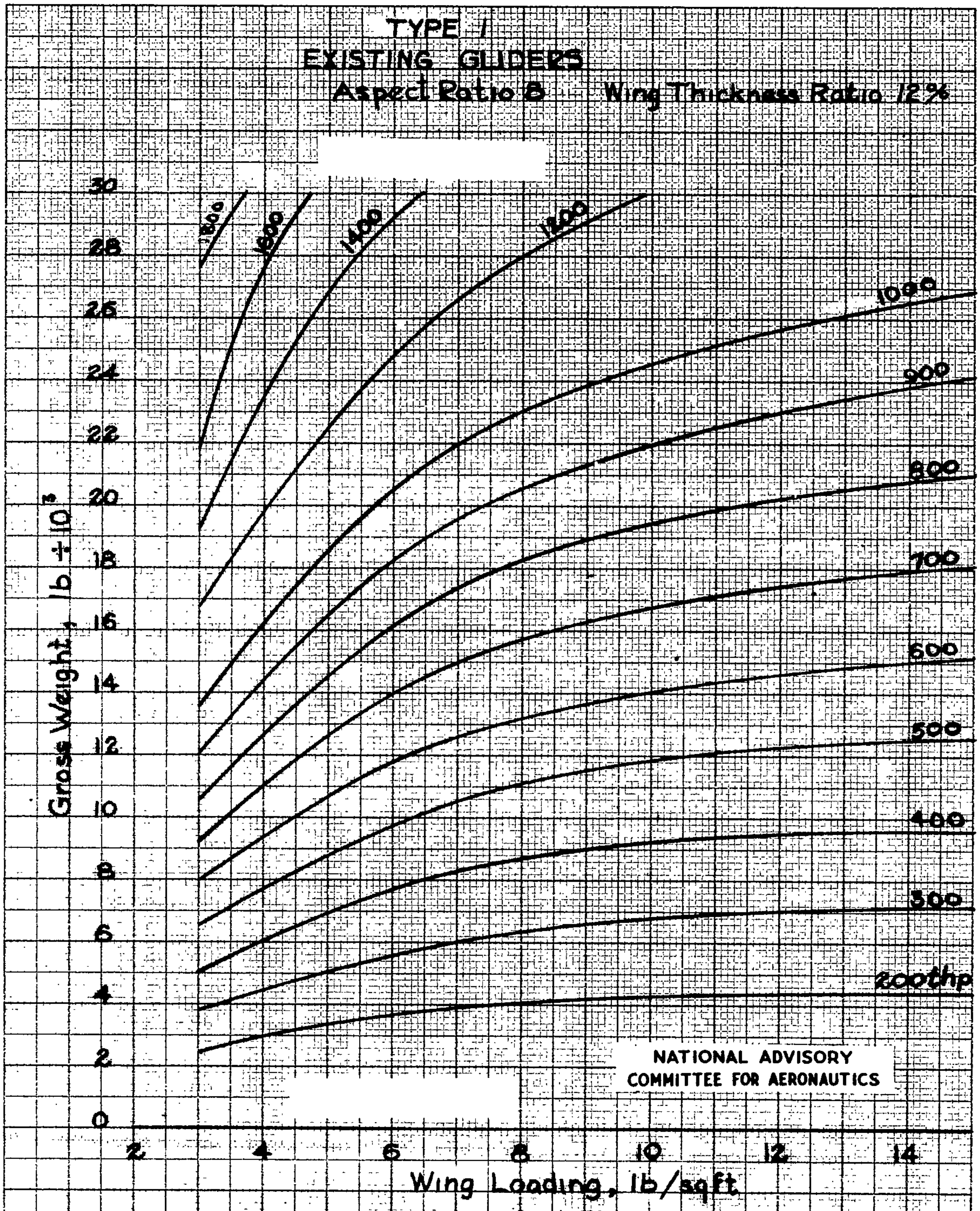

FIGURE 5(c) POWER REQUIRED CLIMBING 500 FT/MIN AT 100 MPH

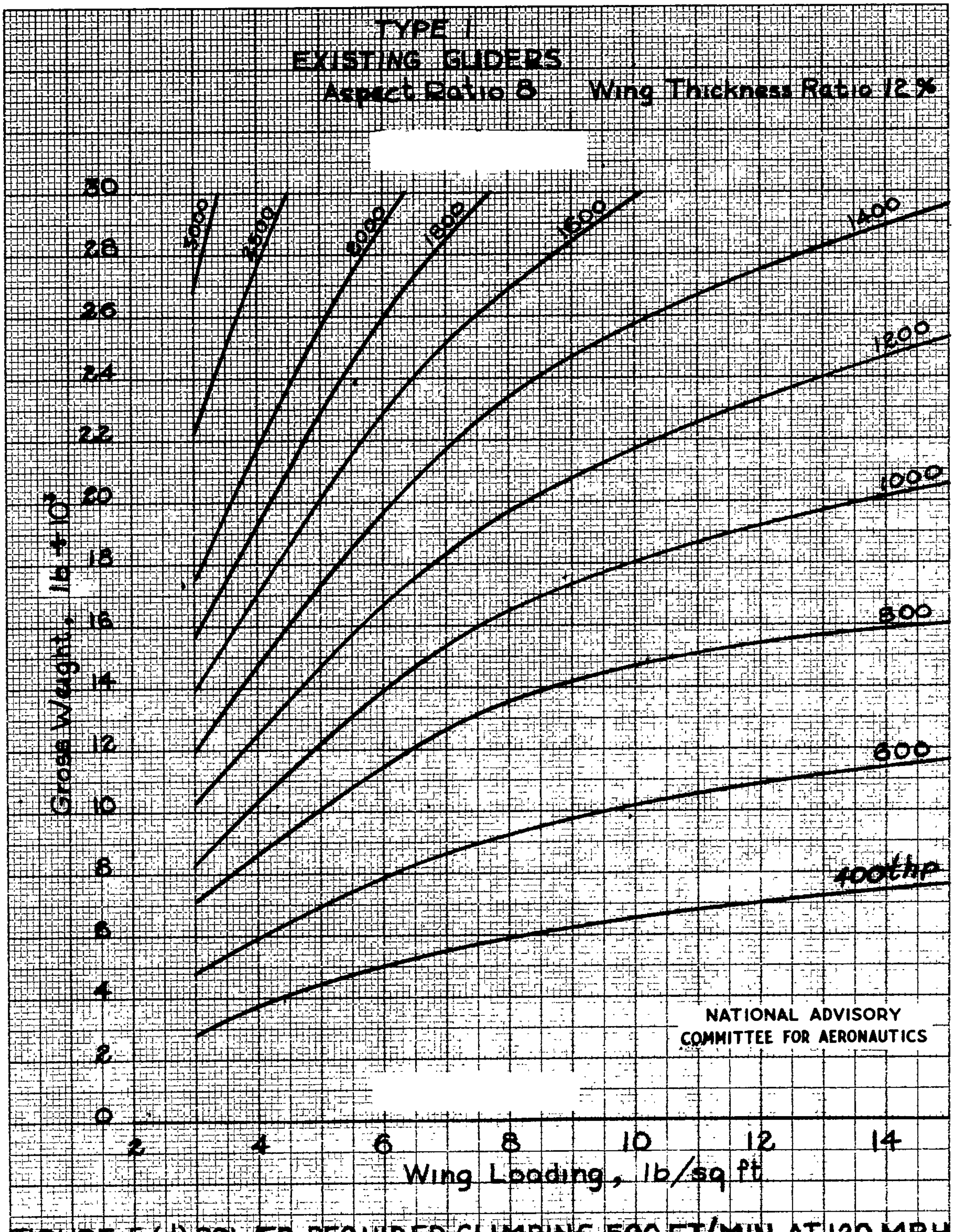

FIGURE 5 (d) POWER REQUIRED CLIMBING 500 FT/MIN AT 120 MPH

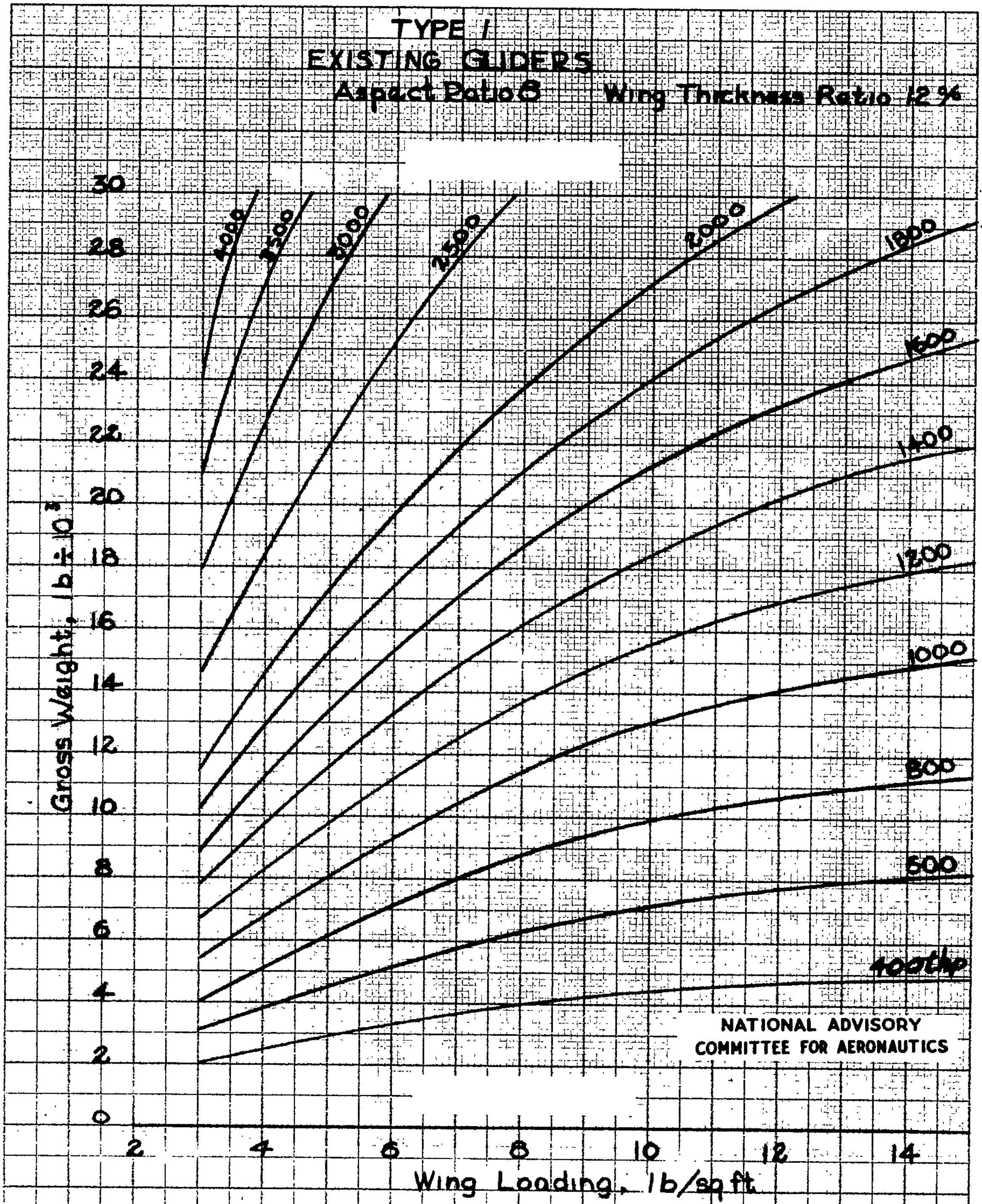

FIGURE 5(e) POWER REQUIRED CLIMBING 500 FT/MIN AT 140 MPH

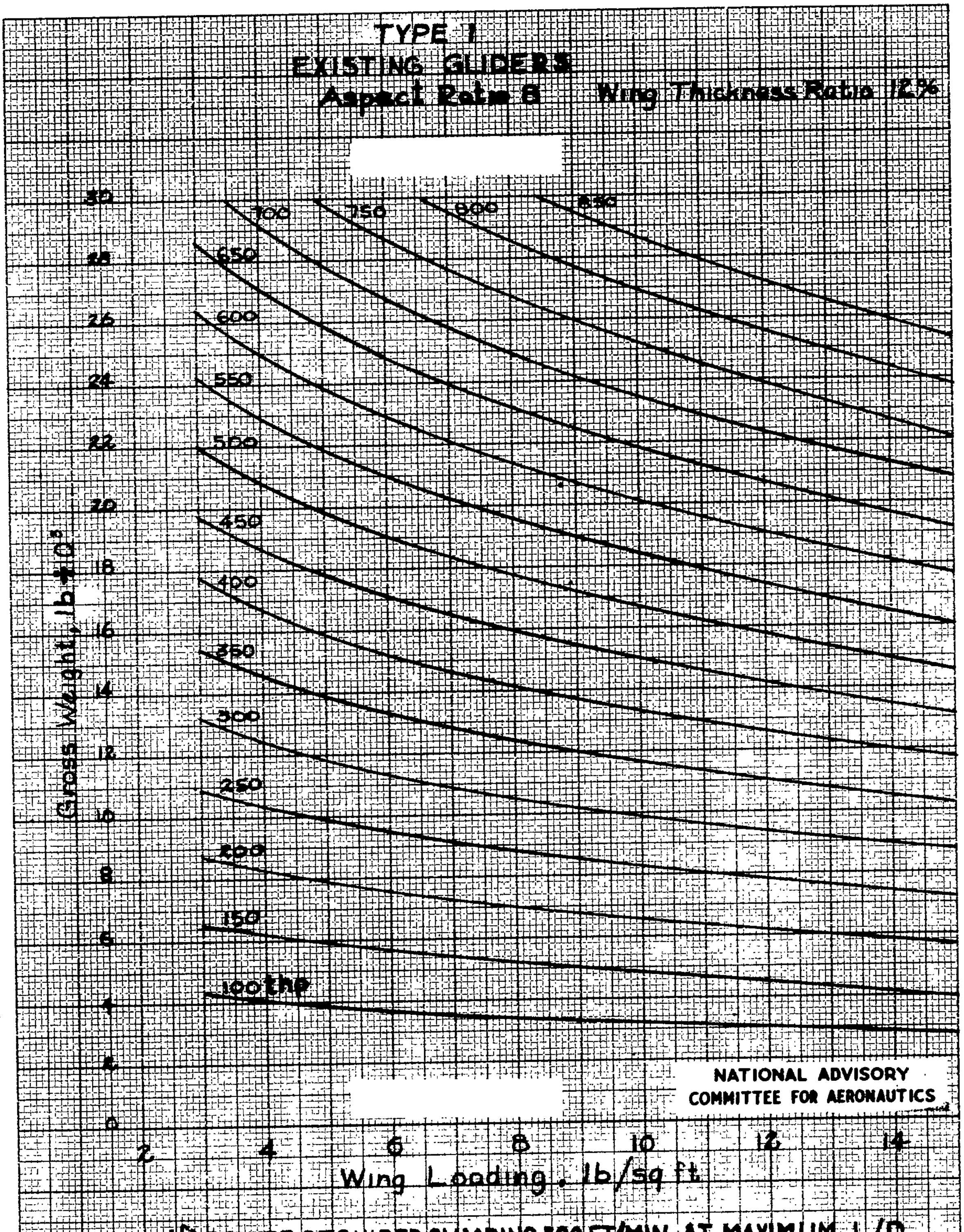

FIGURE 5 (f) POWER REQUIRED CLIMBING 300 FT/MIN AT MAXIMUM L/D

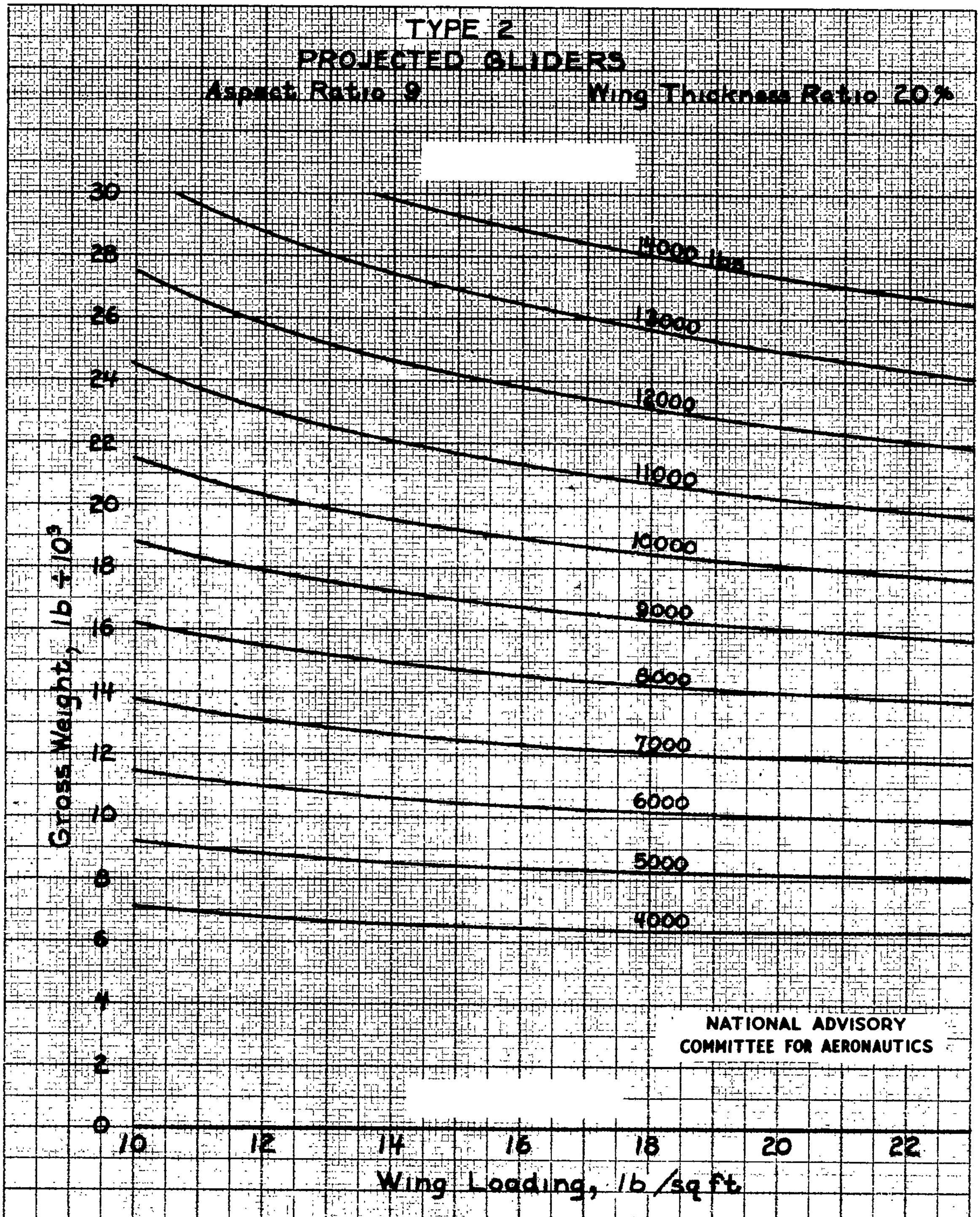

FIGURE 6(a) USEFUL LOAD

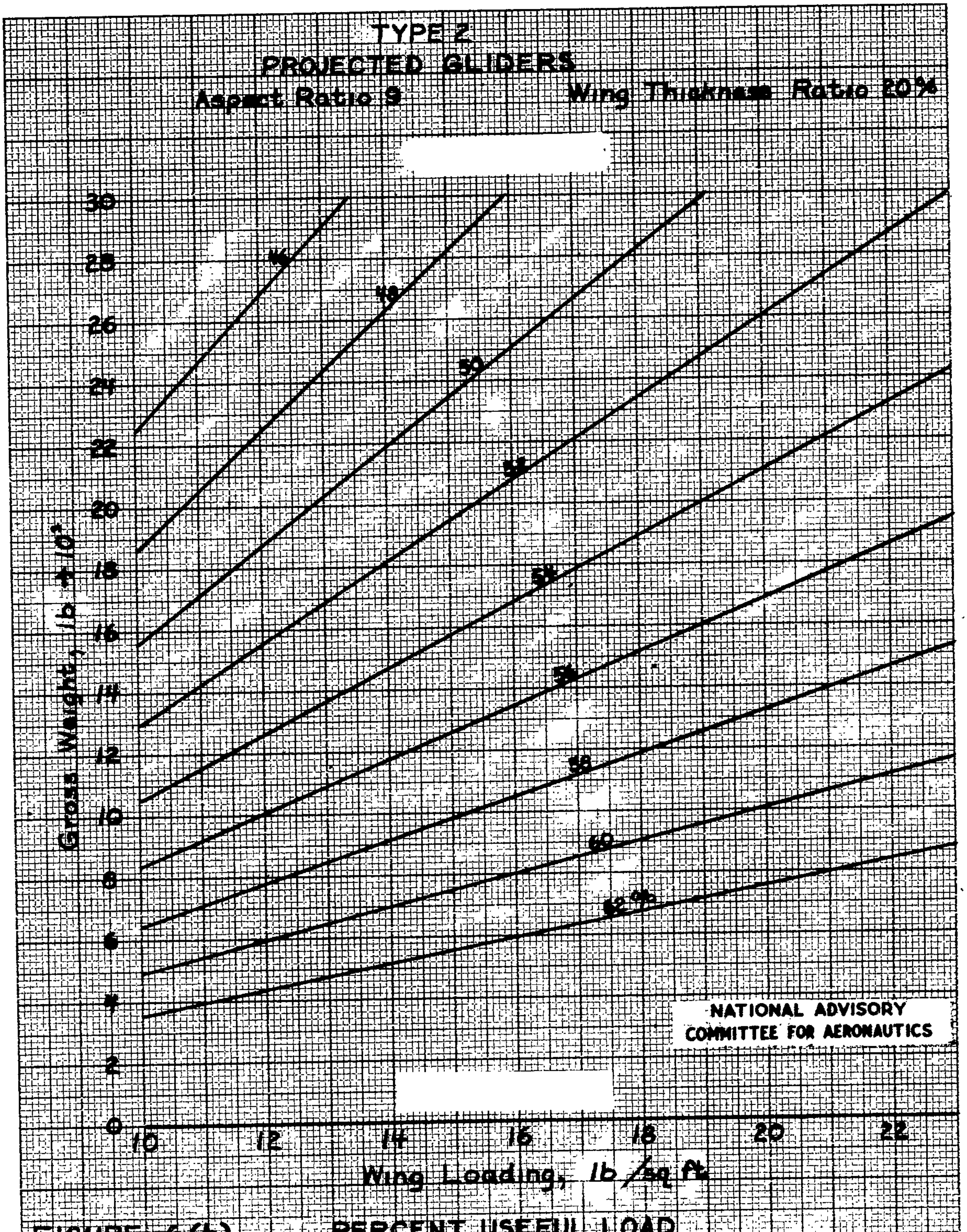

FIGURE 6(b) PERCENT USEFUL LOAD

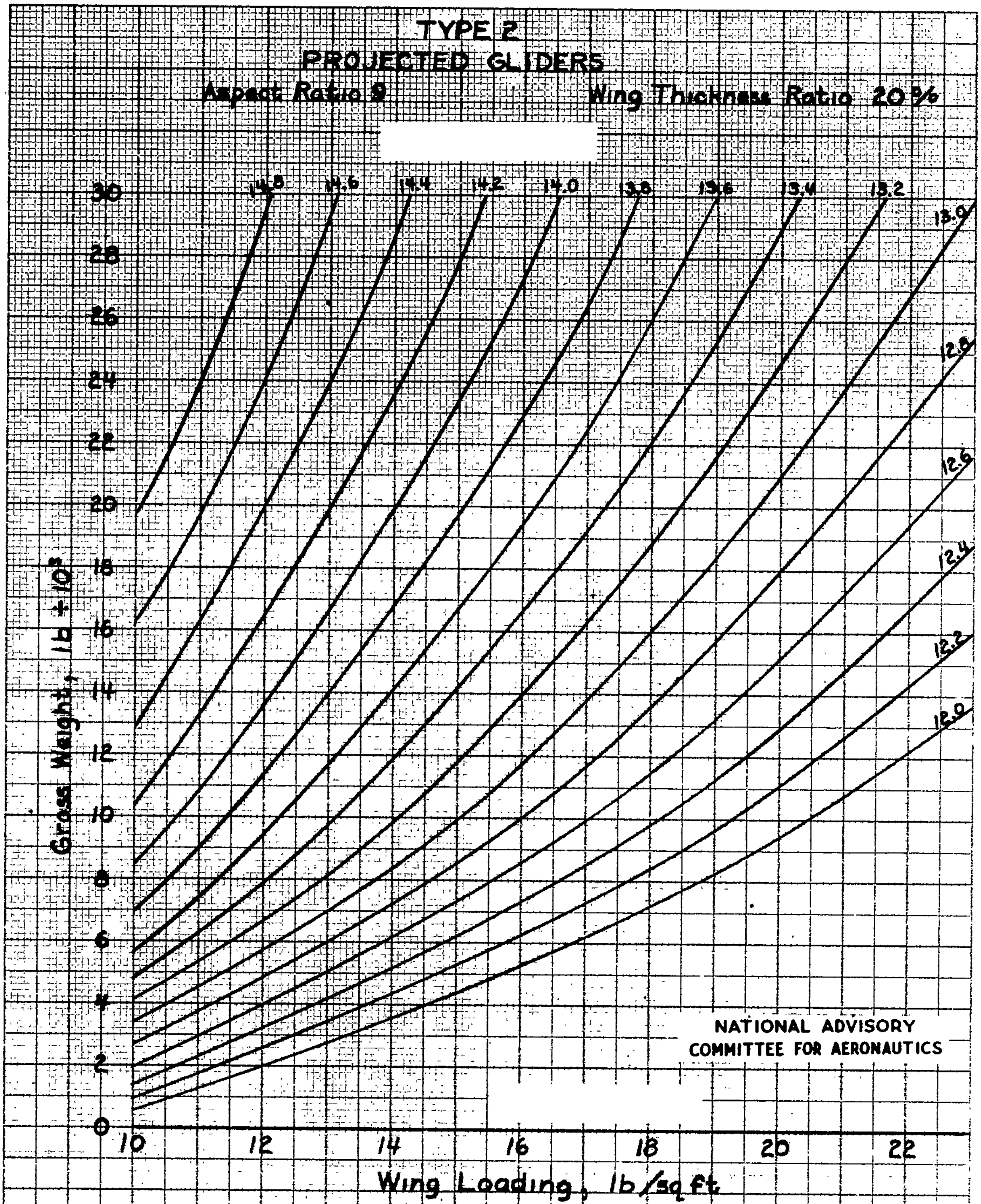

FIGURE 7(a) MAXIMUM GLIDE RATIO

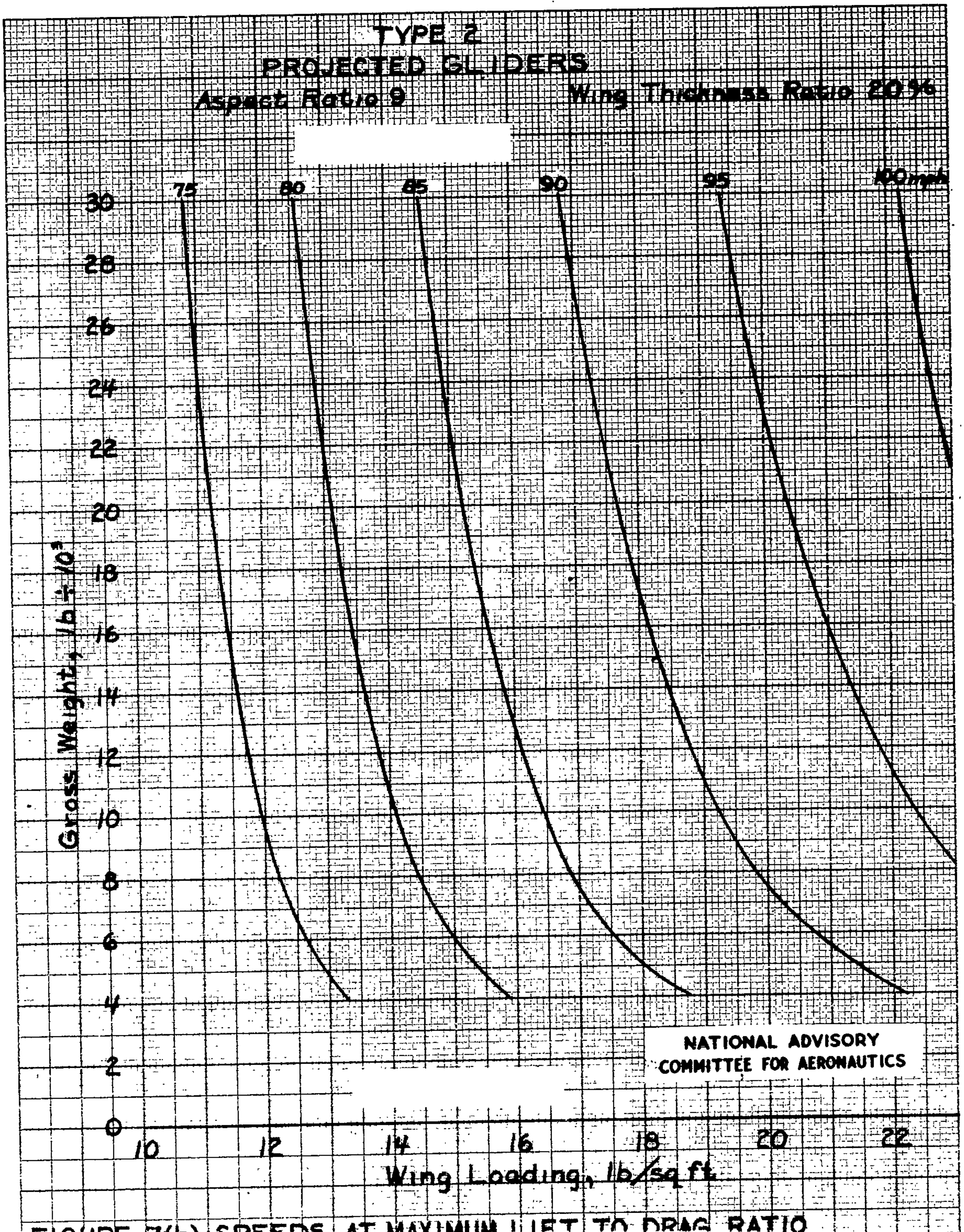

FIGURE 7(b)-SPEEDS AT MAXIMUM LIFT TO DRAG RATIO

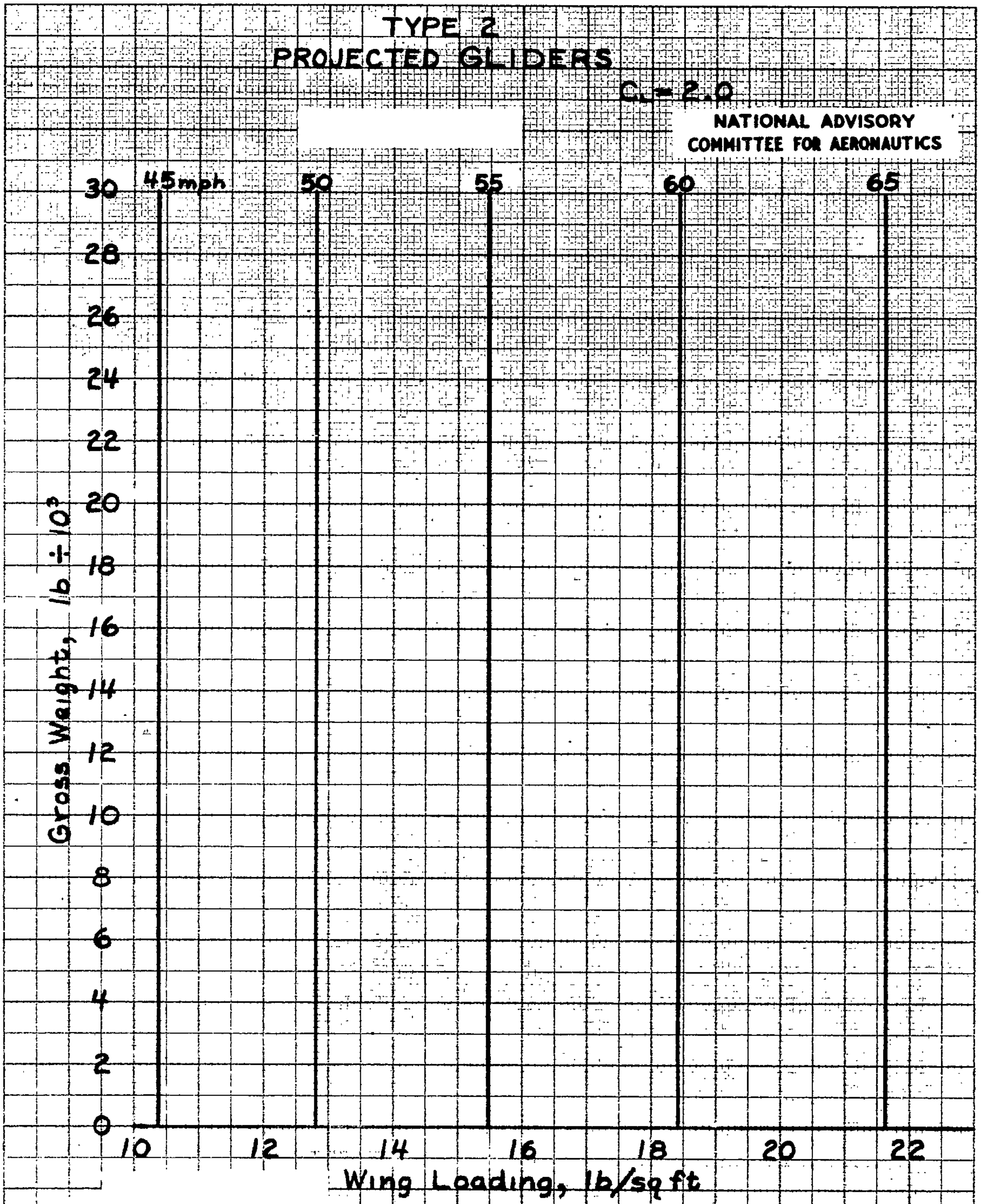

FIGURE 8(a) STALLING SPEEDS WITH FLAPS

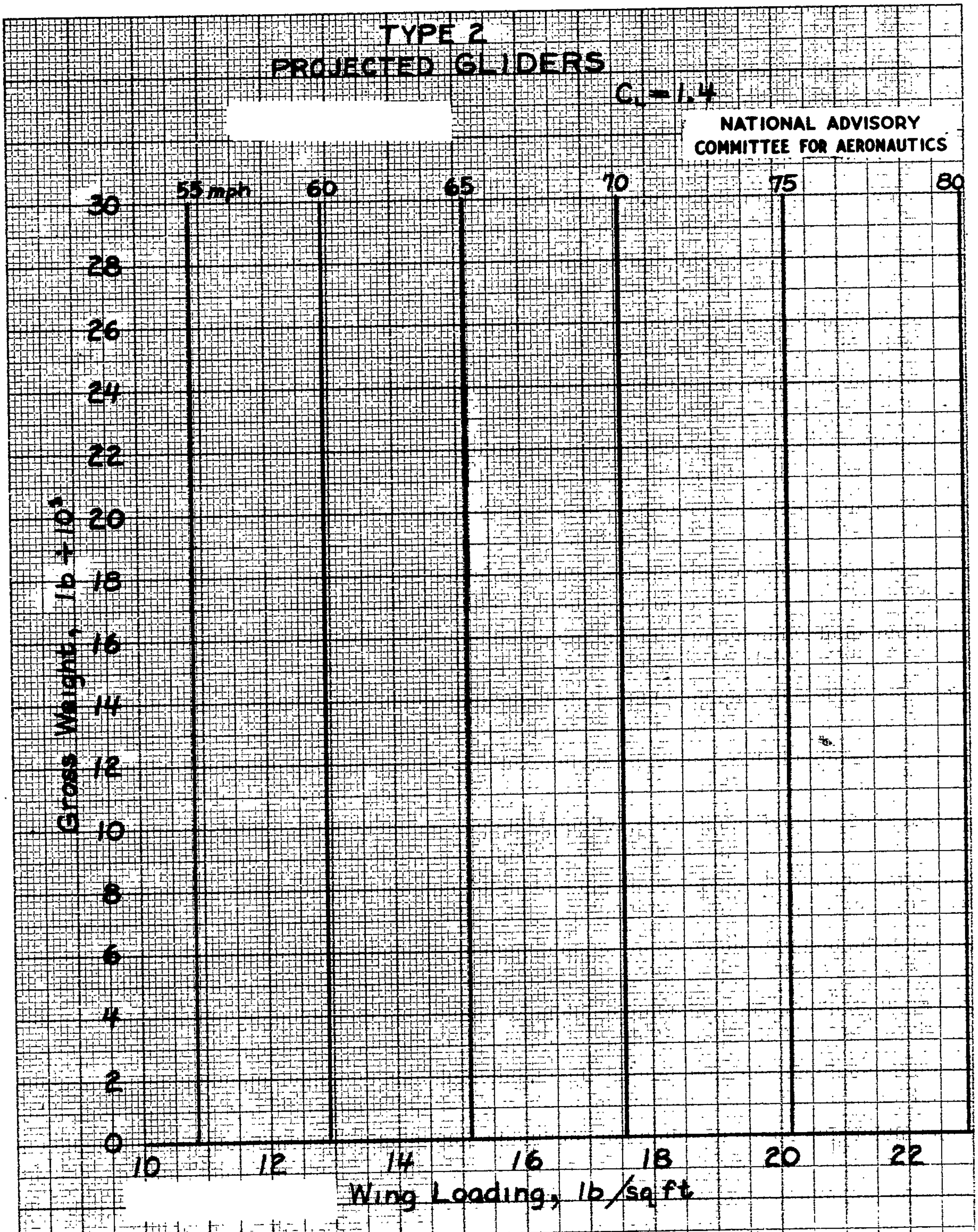

FIGURE 8(b) STALLING SPEEDS WITHOUT FLAPS

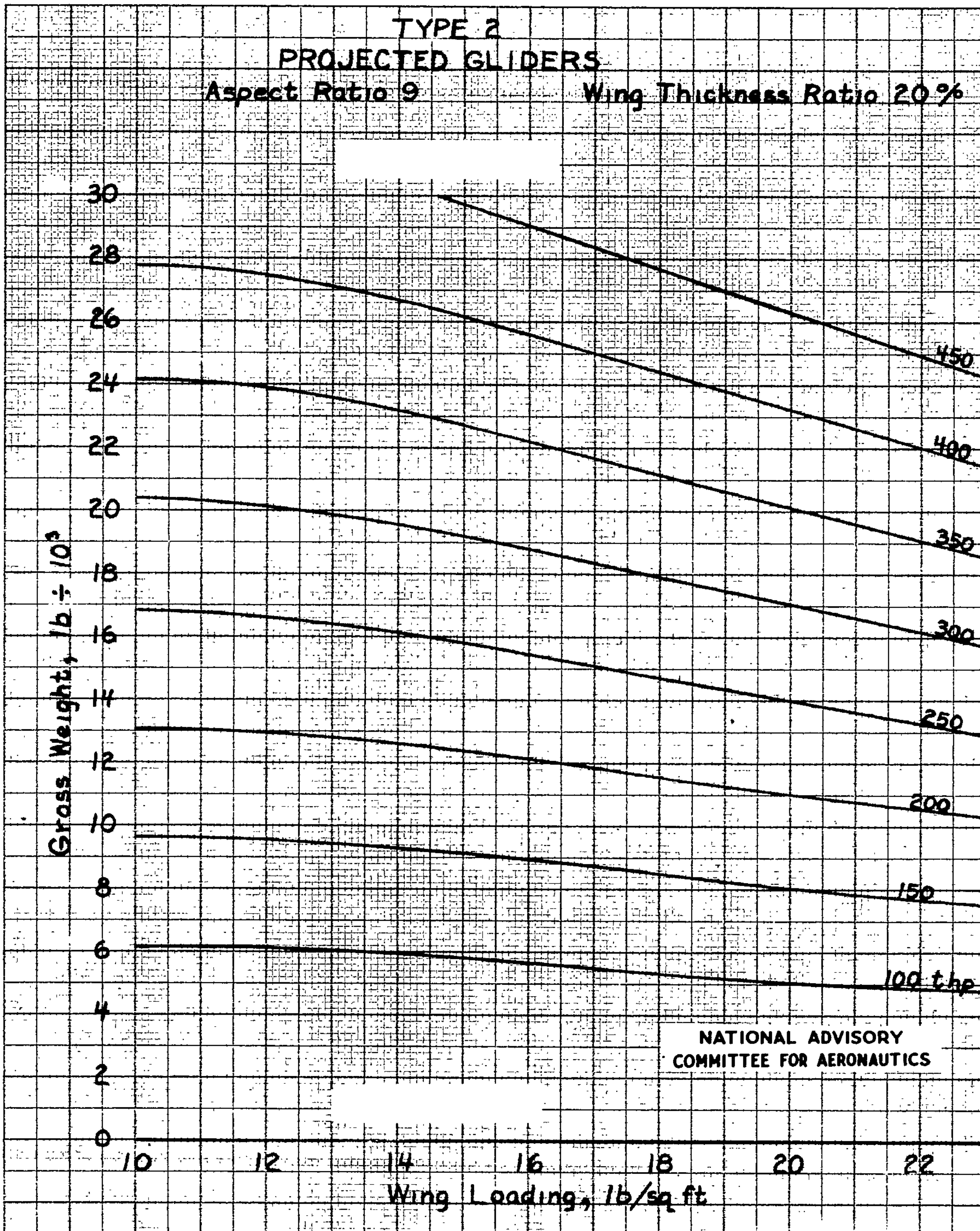

FIGURE 9(a) POWER REQUIRED AT 80 MPH LEVEL

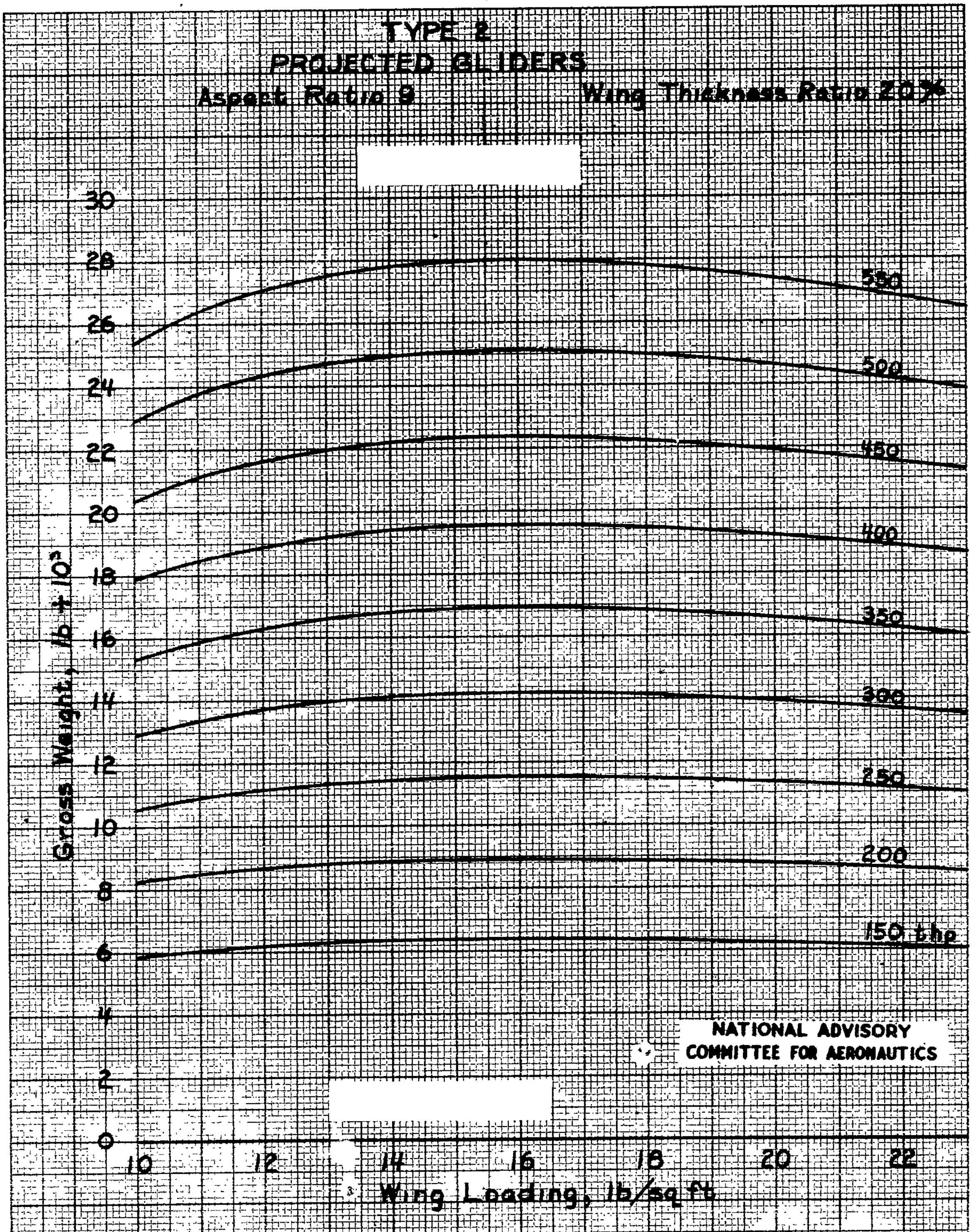

FIGURE 9(b) POWER REQUIRED AT 100 MPH LEVEL

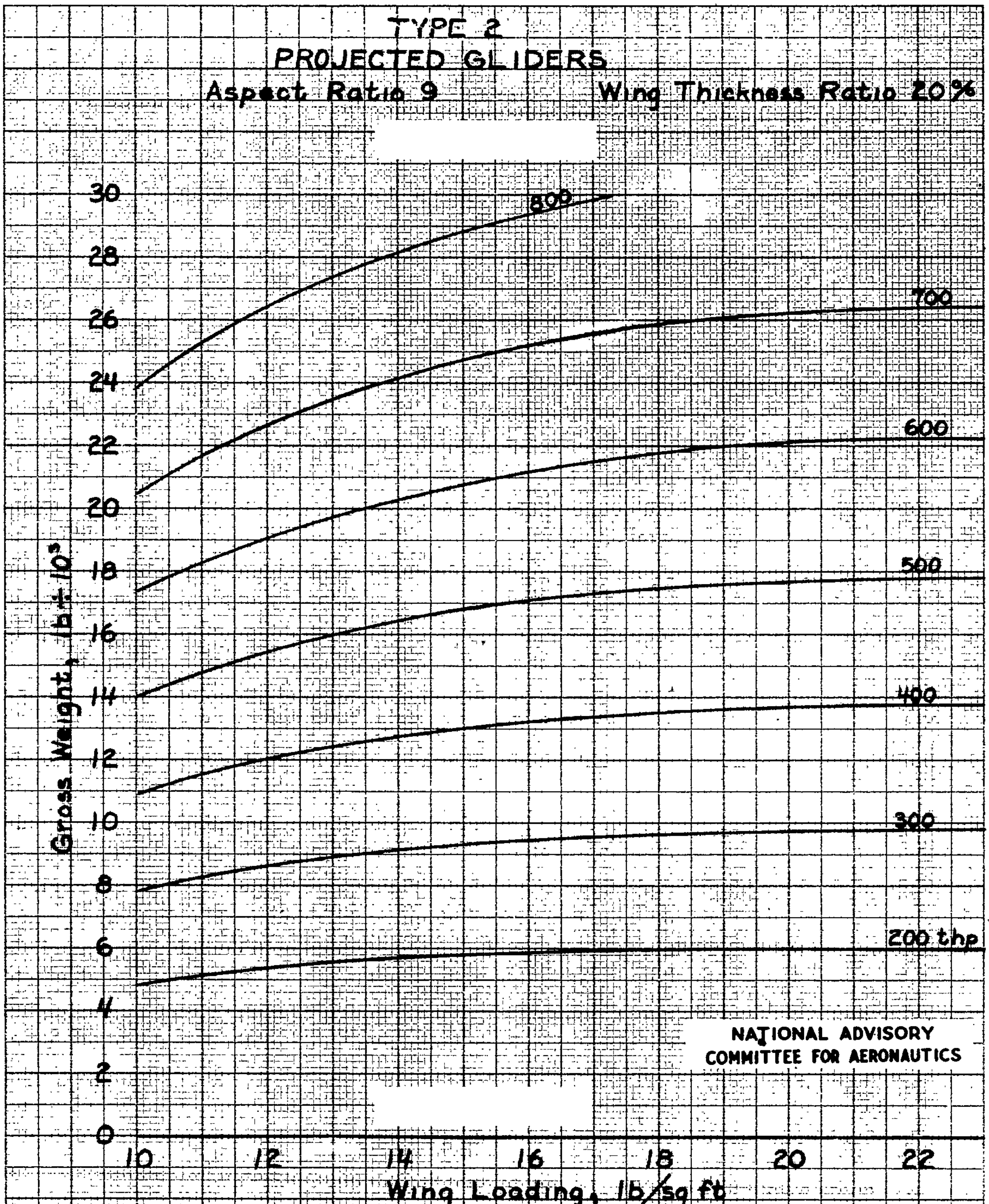

FIGURE 9(c) POWER REQUIRED AT 120 MPH LEVEL

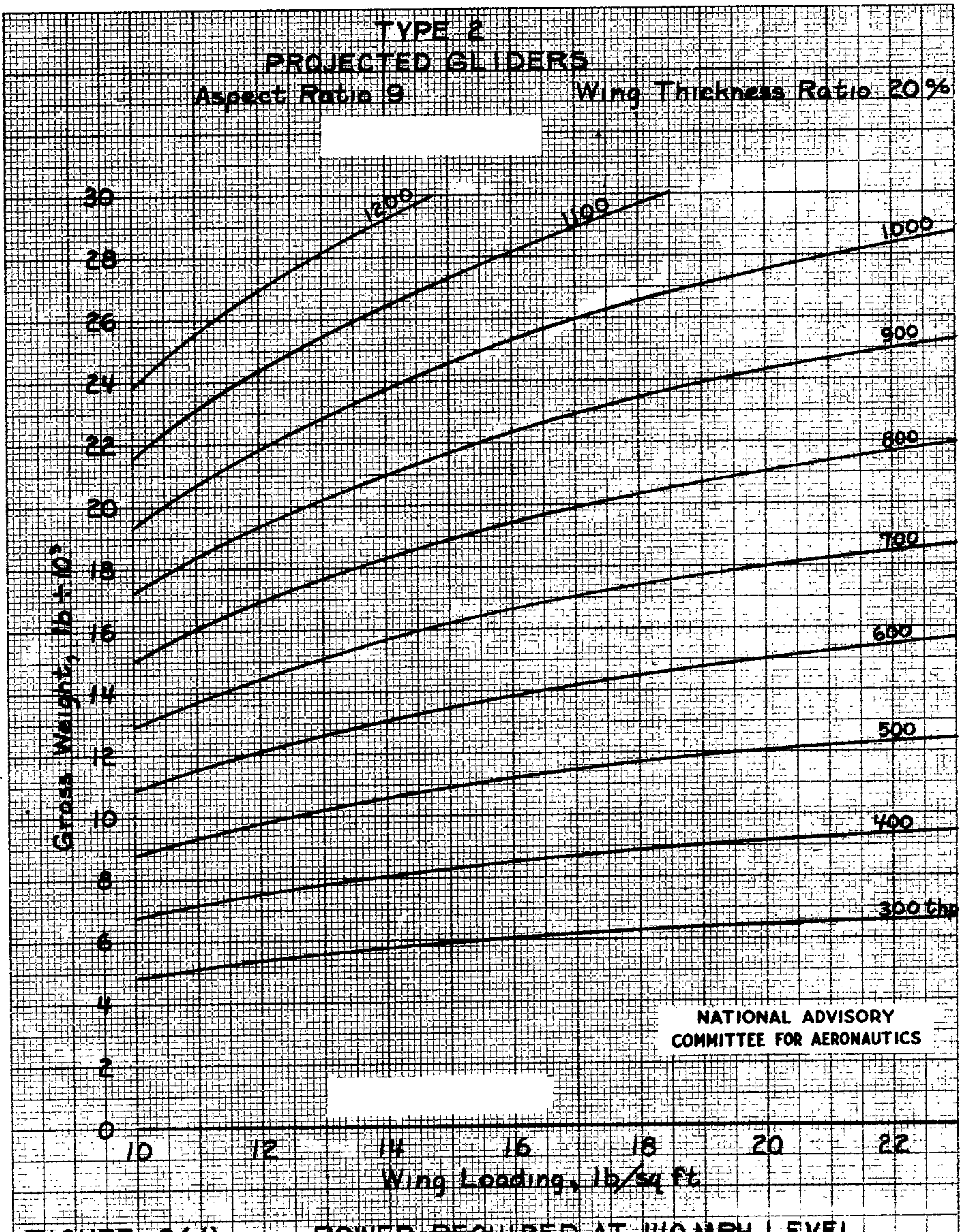

FIGURE 9(d) POWER REQUIRED AT 140 MPH LEVEL

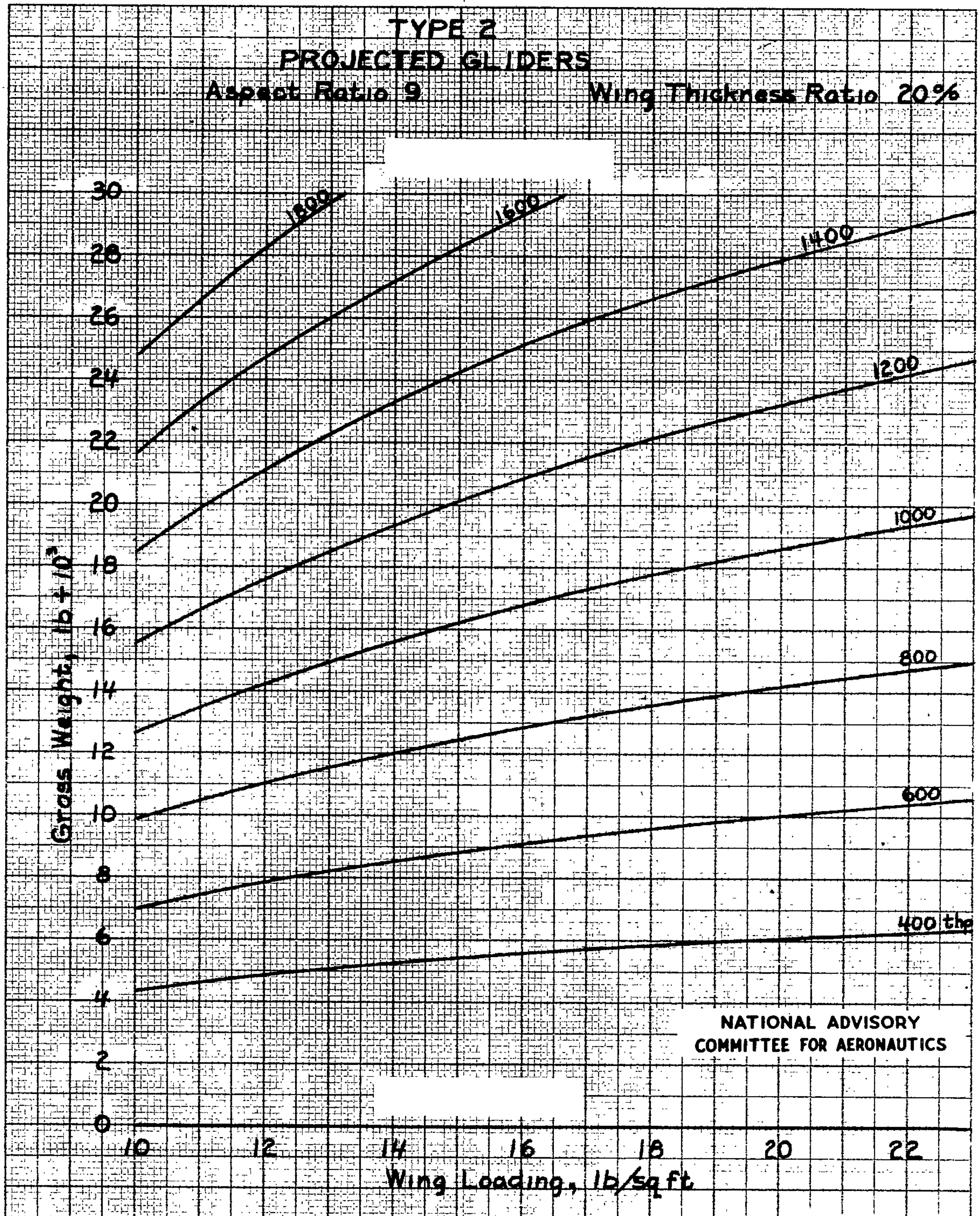

FIGURE 9(e) POWER REQUIRED AT 160 MPH LEVEL

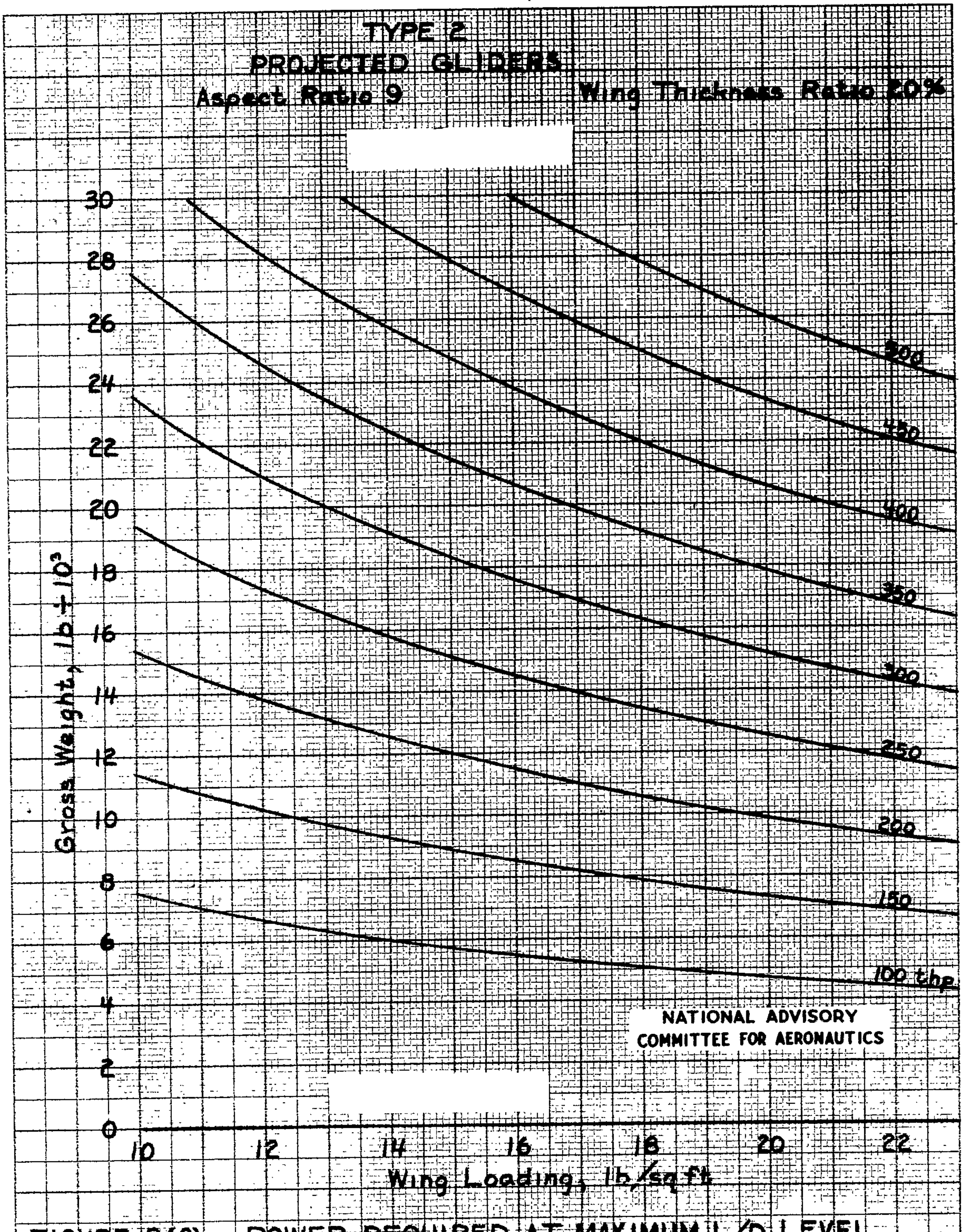

FIGURE 9(f) POWER REQUIRED AT MAXIMUM L/D LEVEL

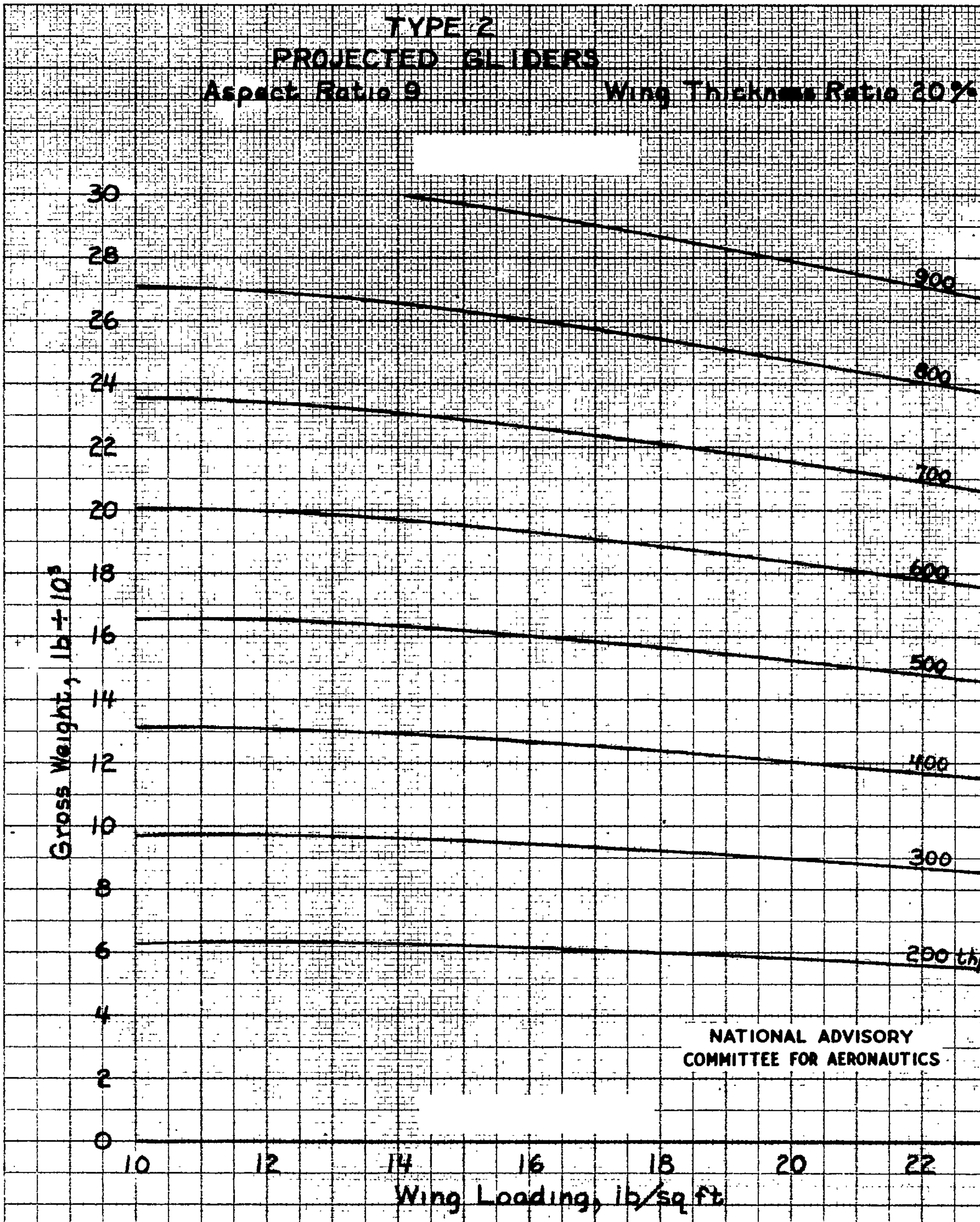

FIGURE 10(a)- POWER REQUIRED CLIMBING 500 FT/MIN AT 80 MPH

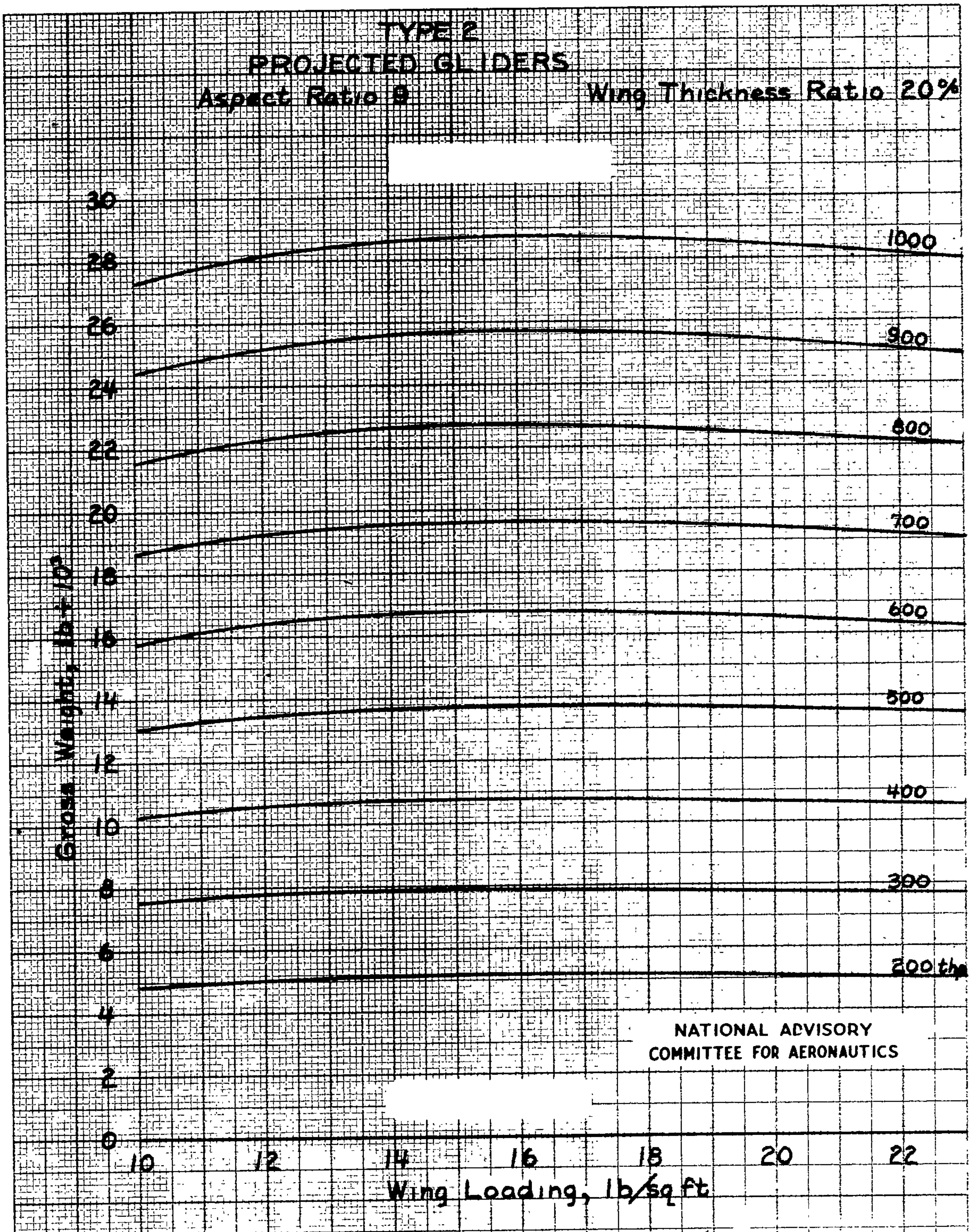

FIGURE 10(b) POWER REQUIRED CLIMBING 500 FT/MIN AT 100 MPH

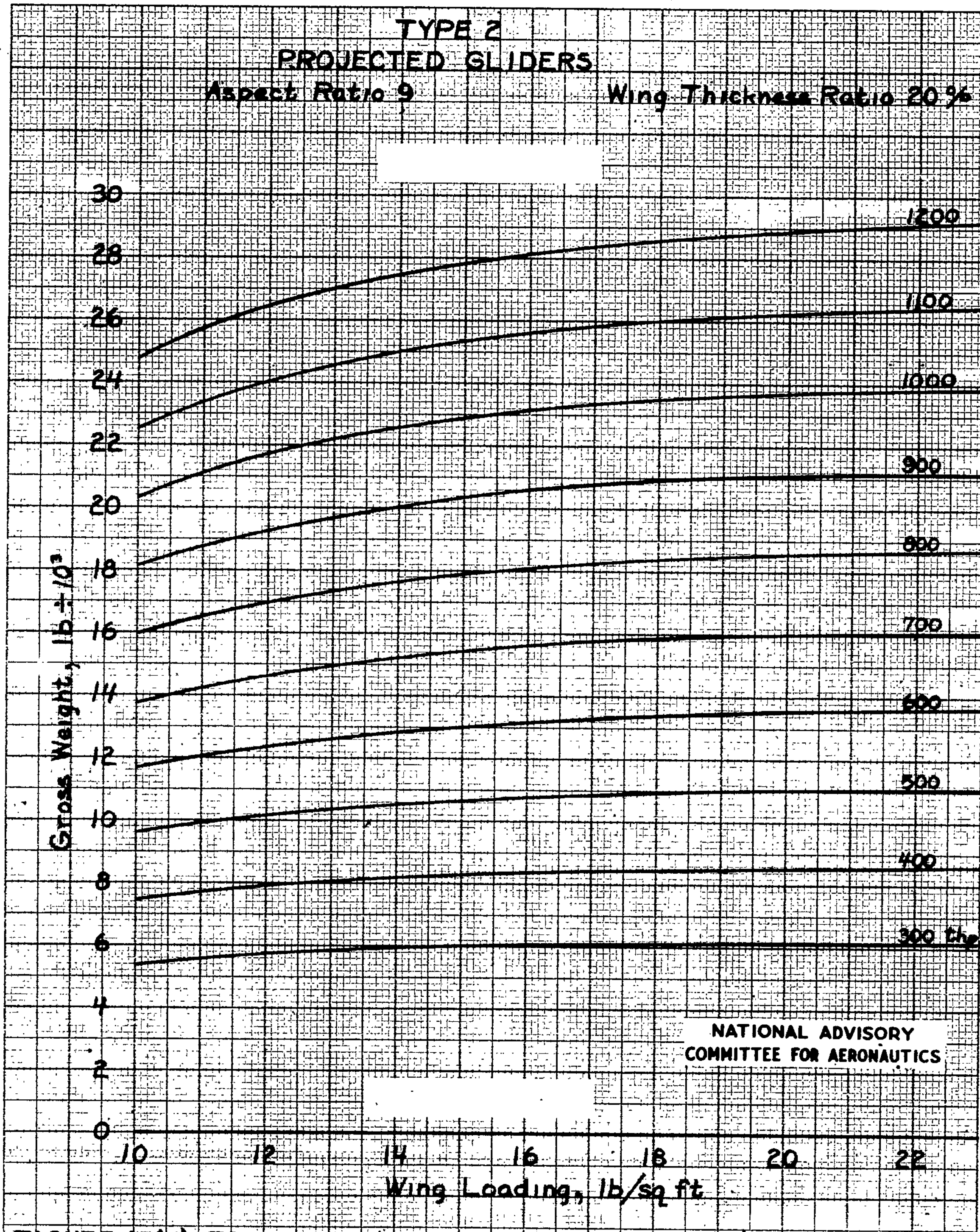

FIGURE 10(c) POWER REQUIRED CLIMBING 500 FT/MIN AT 120 MPH

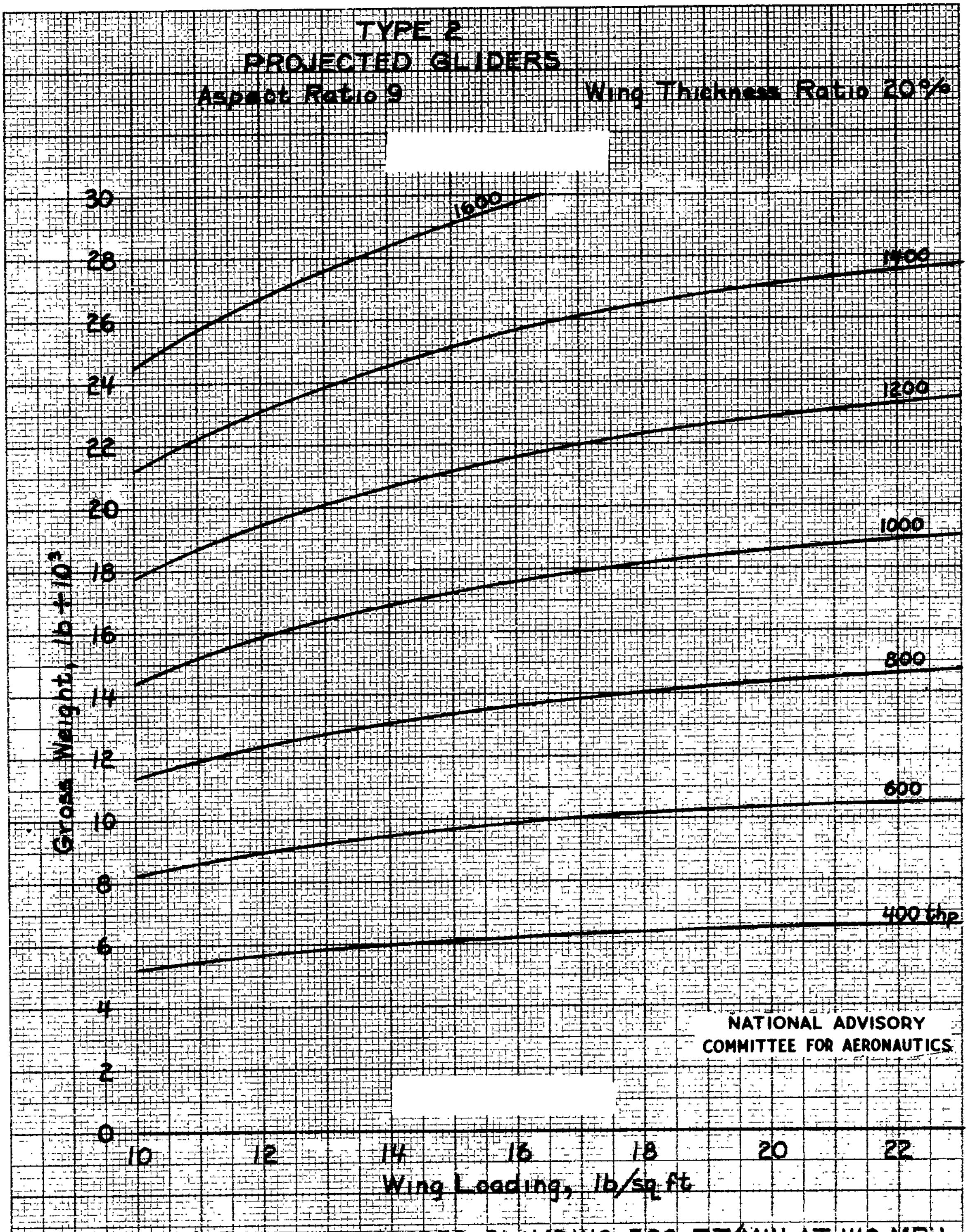

FIGURE 10(d) POWER REQUIRED CLIMBING 500 FT/MIN AT 140 MPH

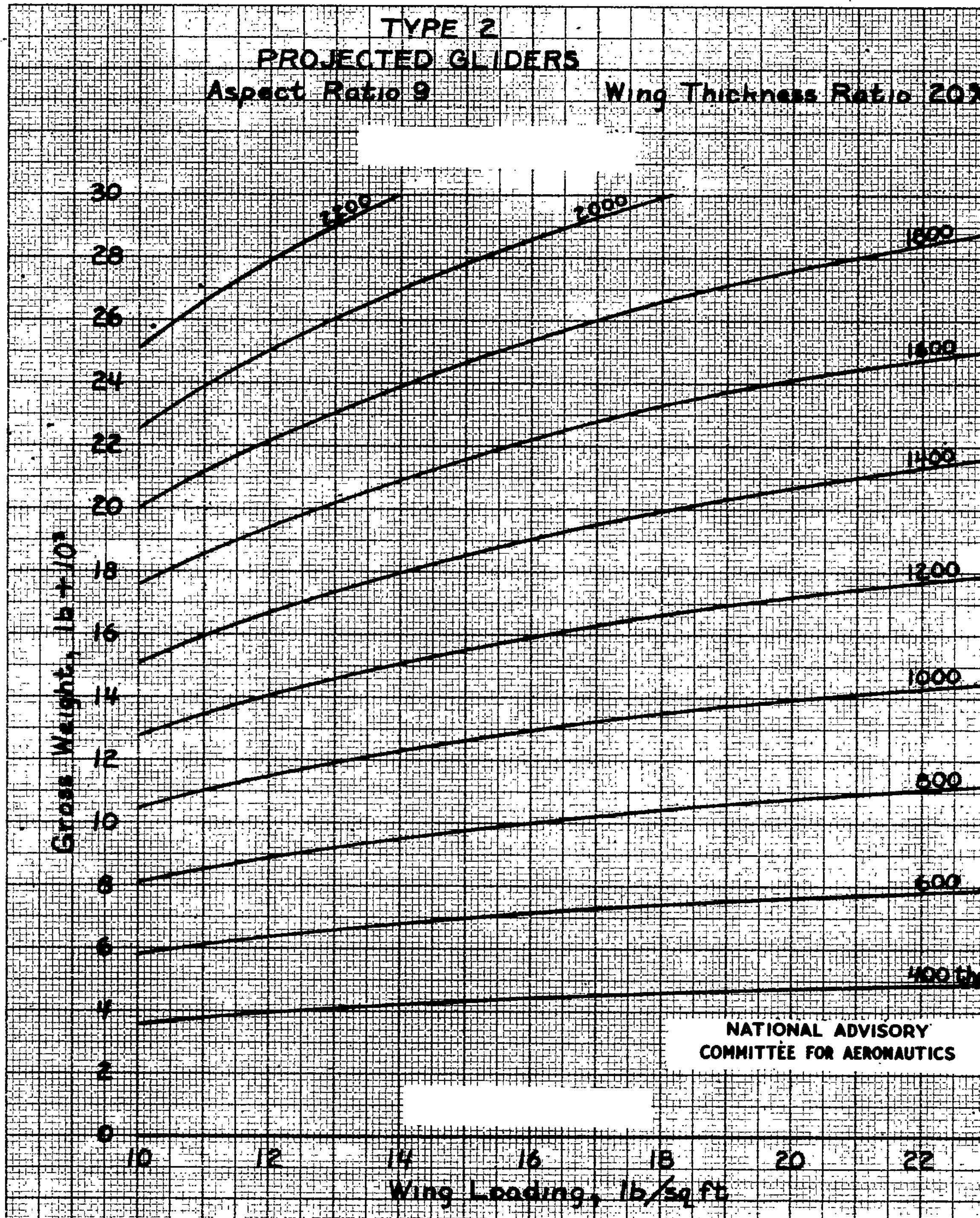

FIGURE 10(e) POWER REQUIRED CLIMBING 500 FT/MIN AT 160 MPH

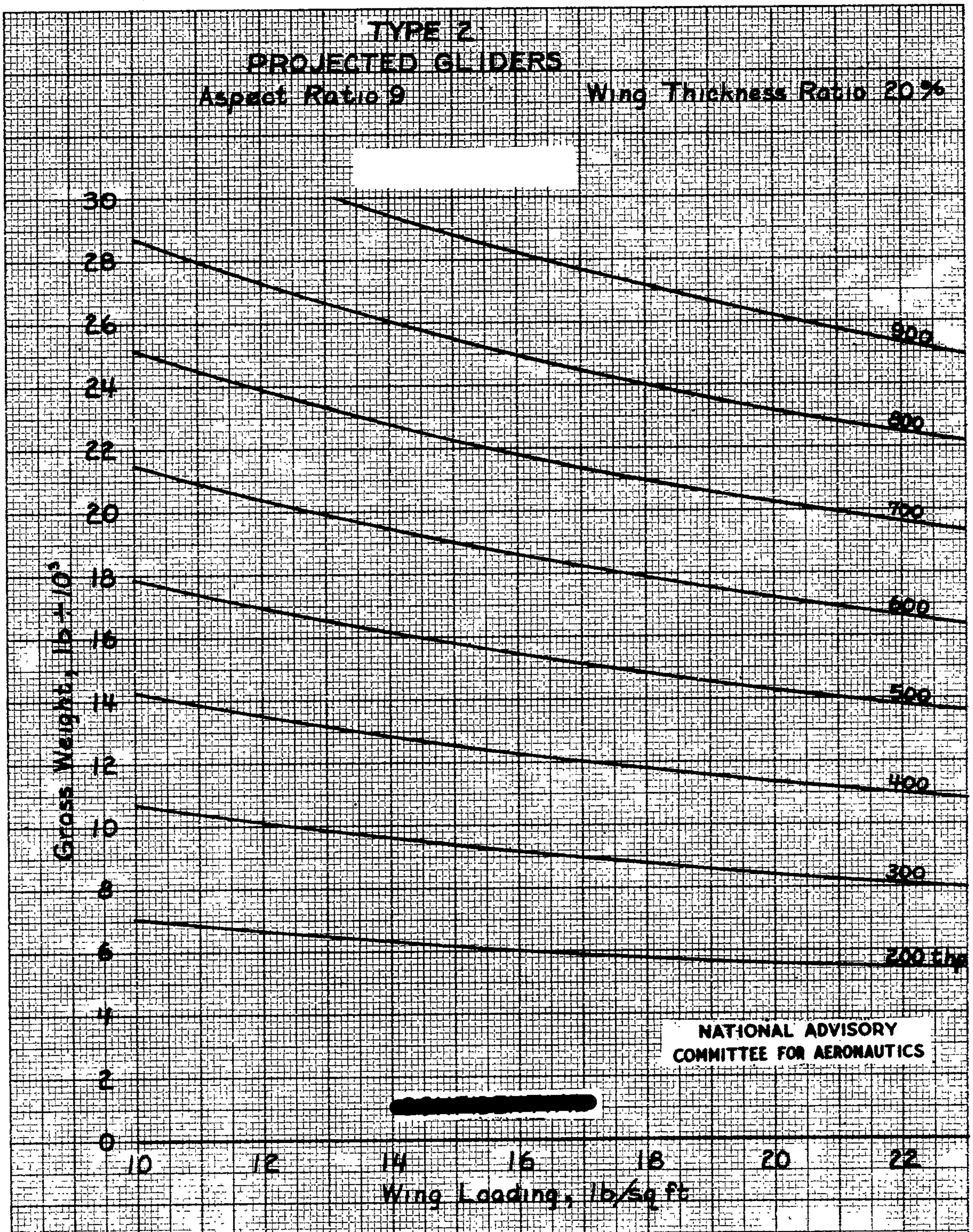

FIGURE 10(f)- POWER REQUIRED CLIMBING 500 FT/MIN AT MAXIMUM L/D

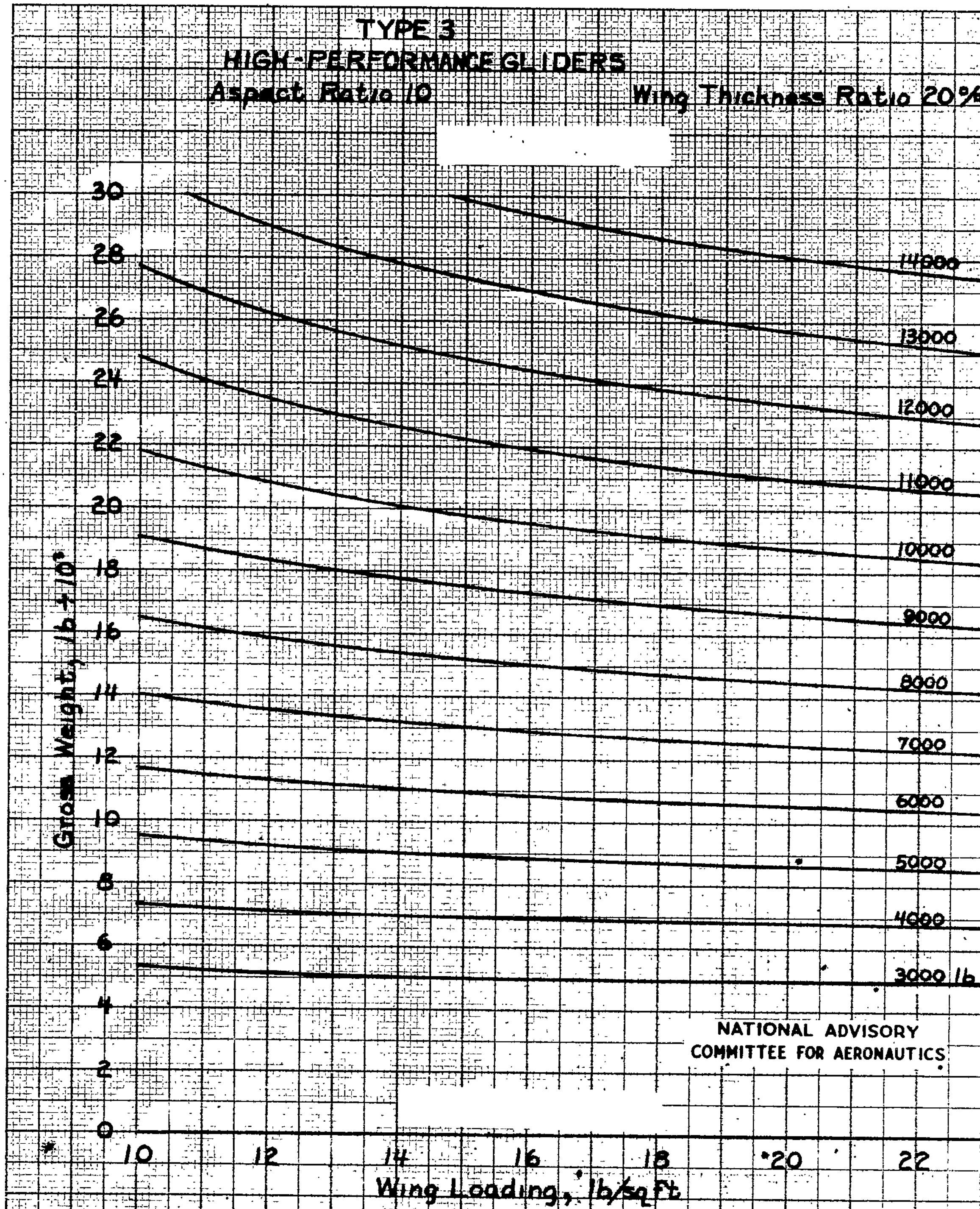

FIGURE 11(a) USEFUL LOAD

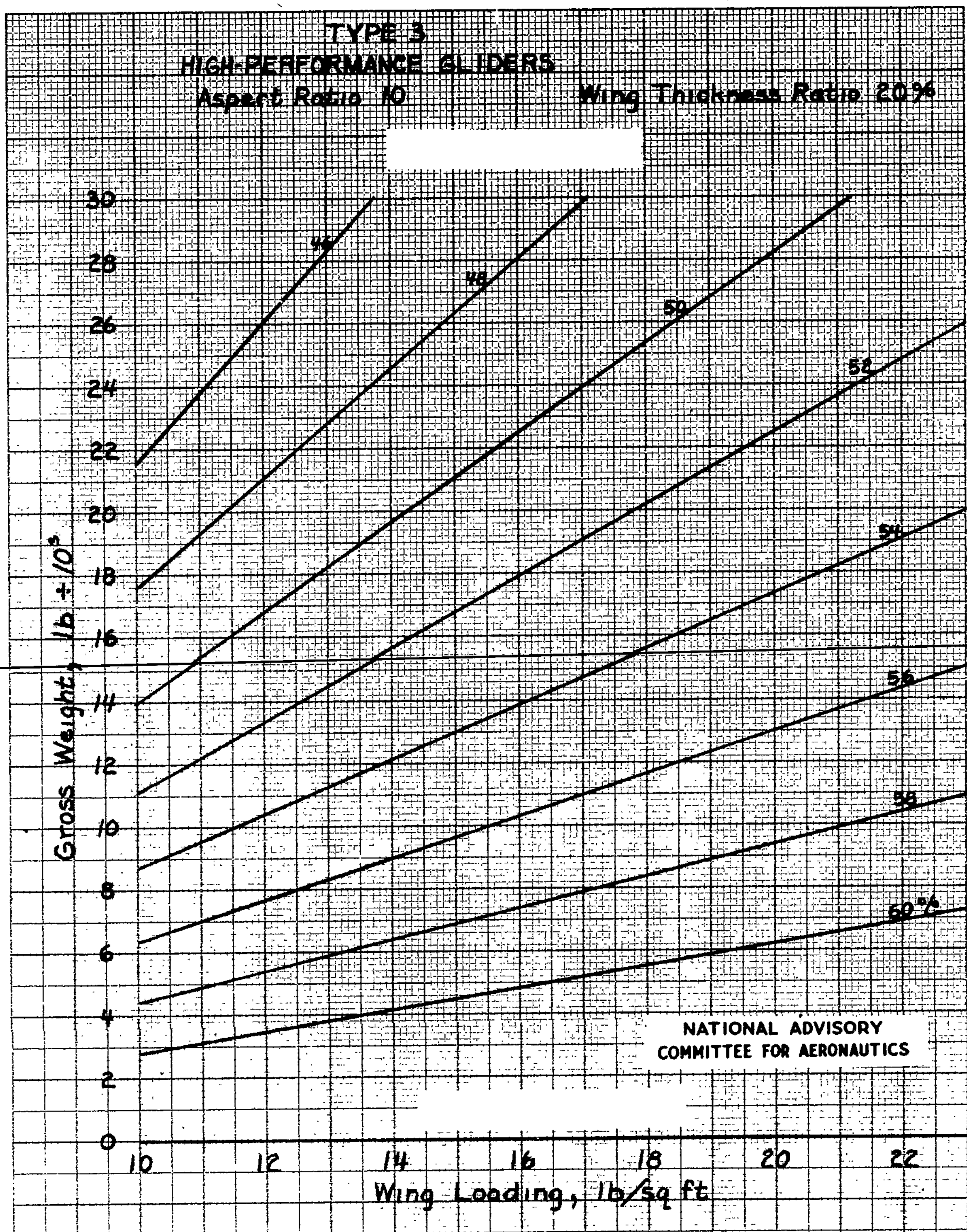

FIGURE 11(b)   PERCENT USEFUL LOAD

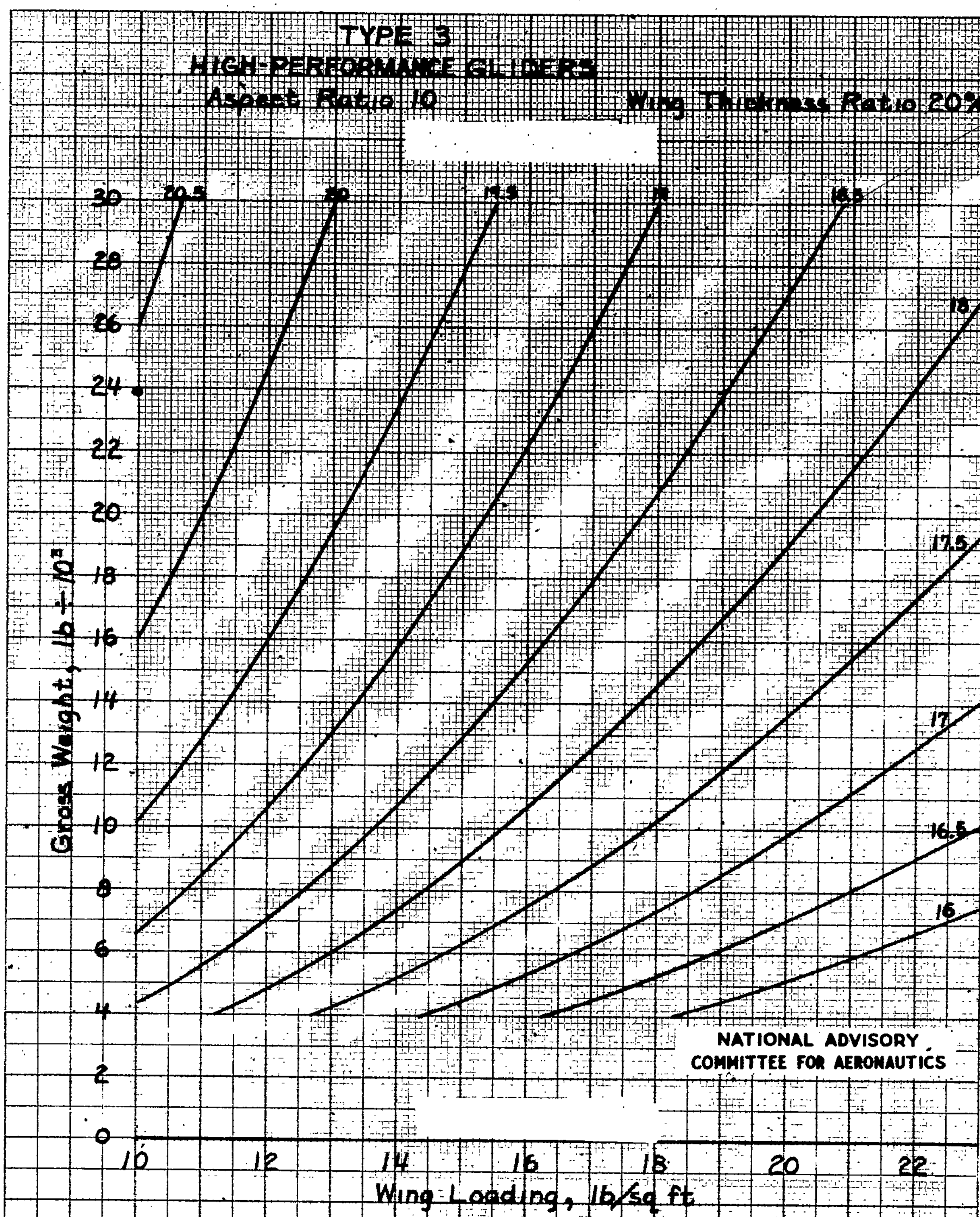

FIGURE 12(a) MAXIMUM GLIDE RATIO

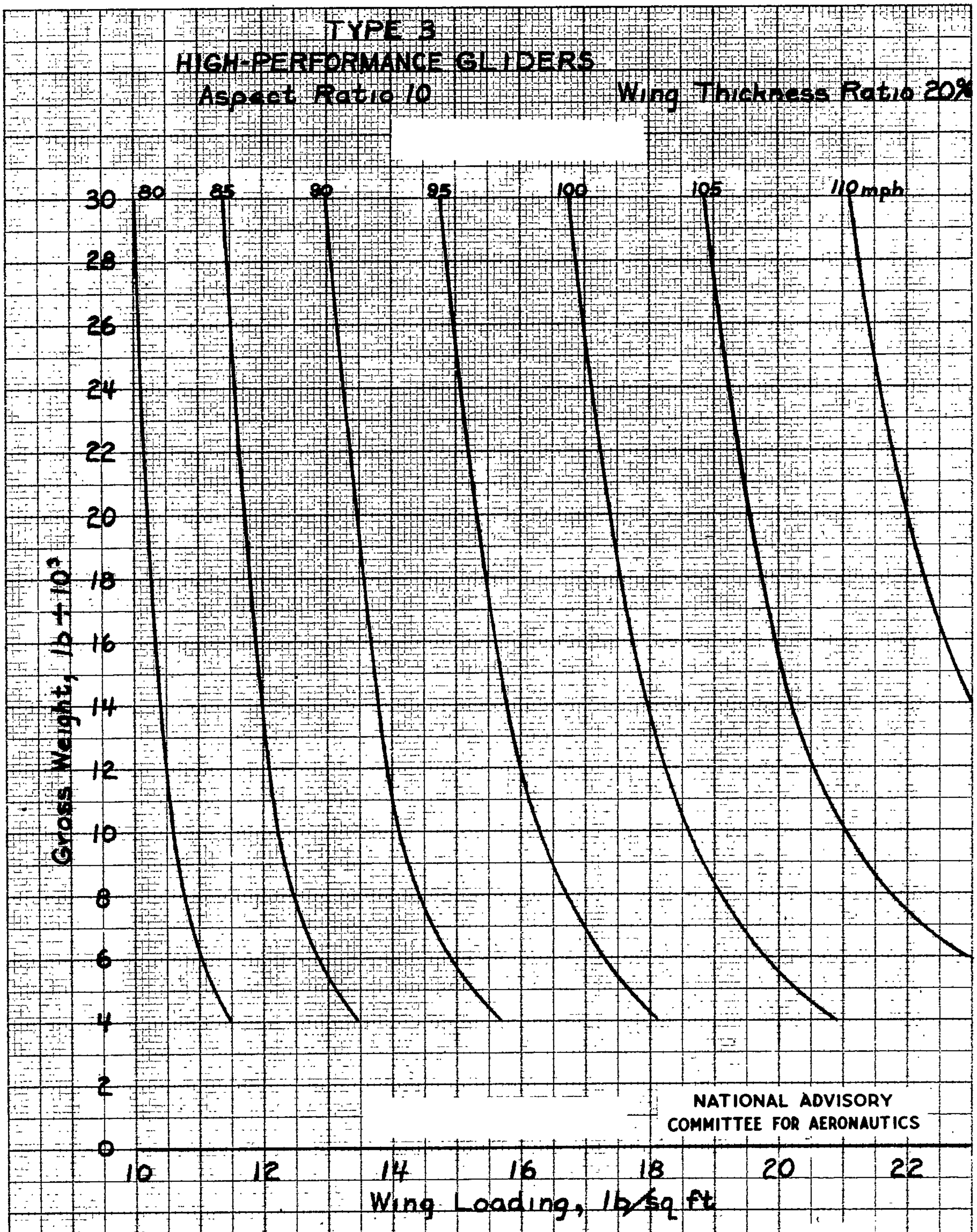

FIGURE 12(b) SPEEDS AT MAXIMUM LIFT TO DRAG RATIO

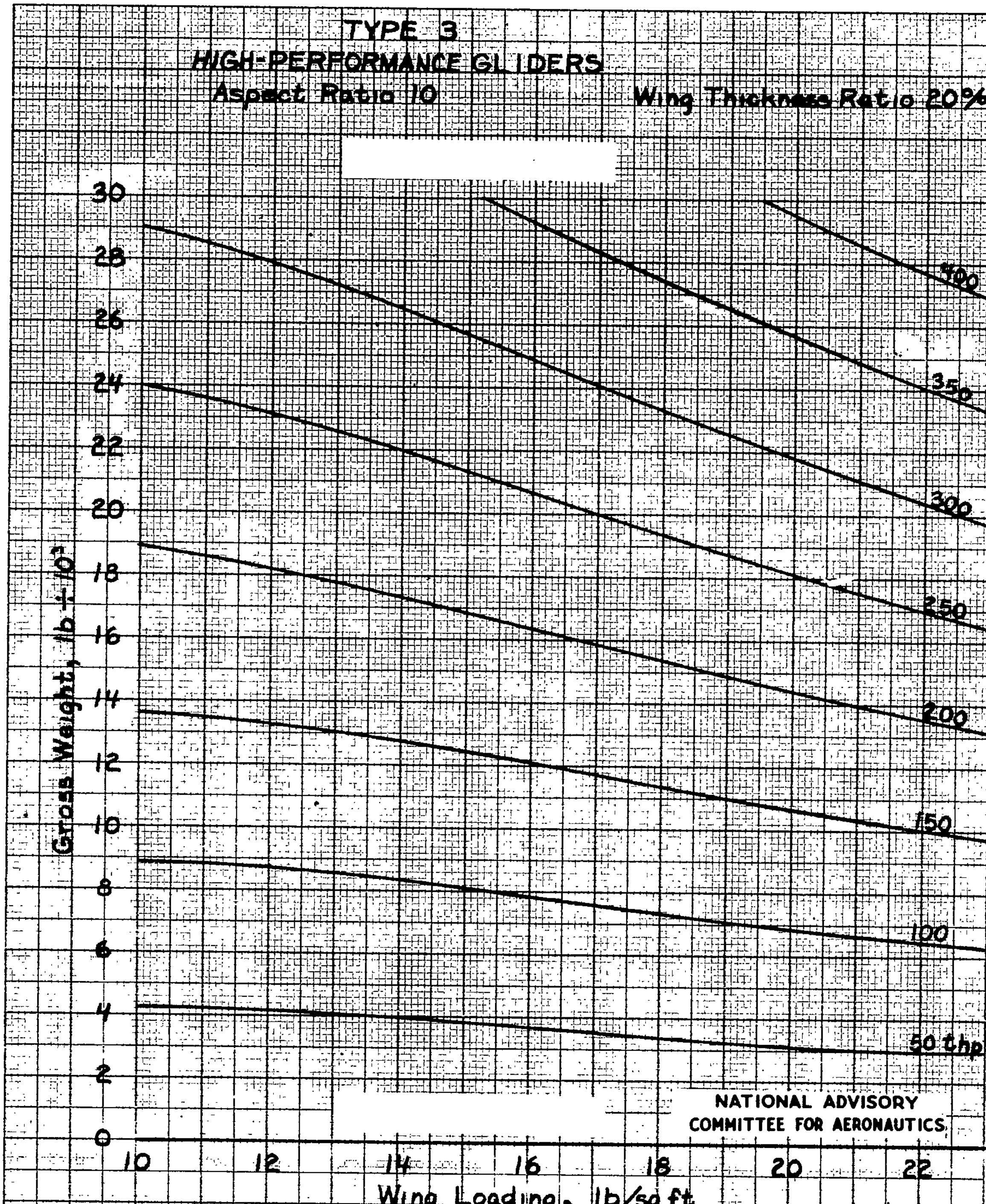

FIGURE 13(a) POWER REQUIRED AT 80 MPH LEVEL

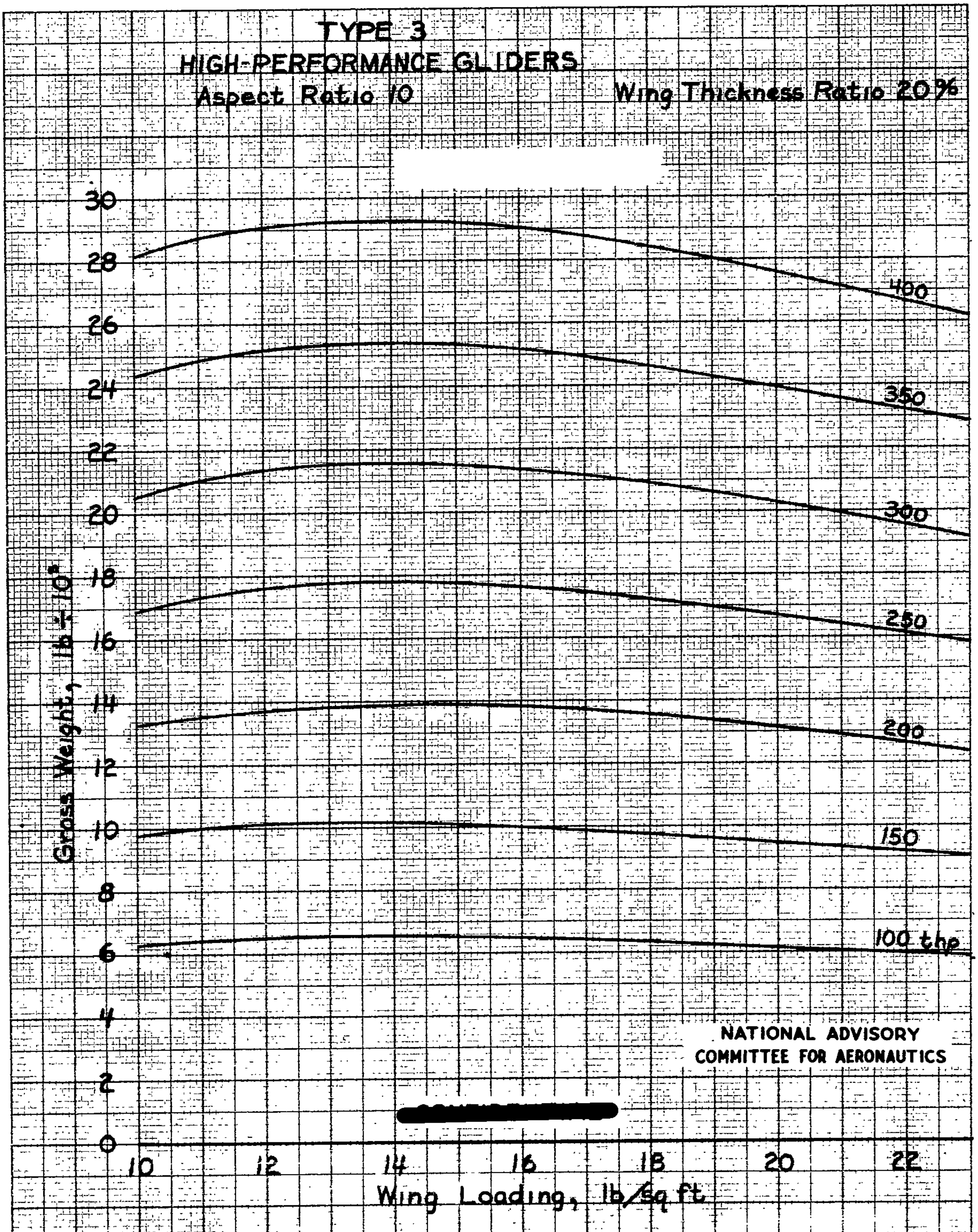

FIGURE 13(b) POWER REQUIRED AT 100 MPH LEVEL

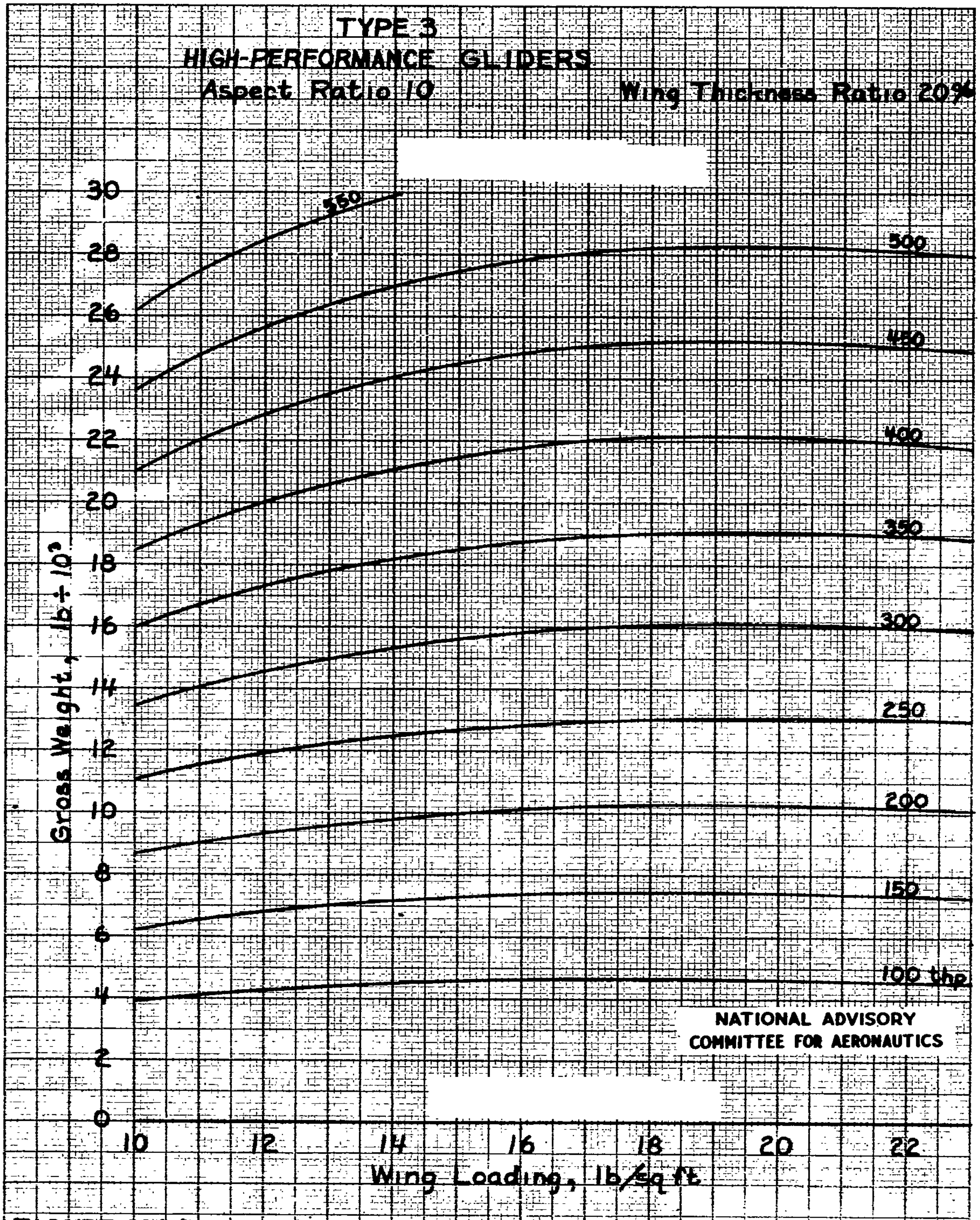

FIGURE 13(c) POWER REQUIRED AT 120 MPH LEVEL

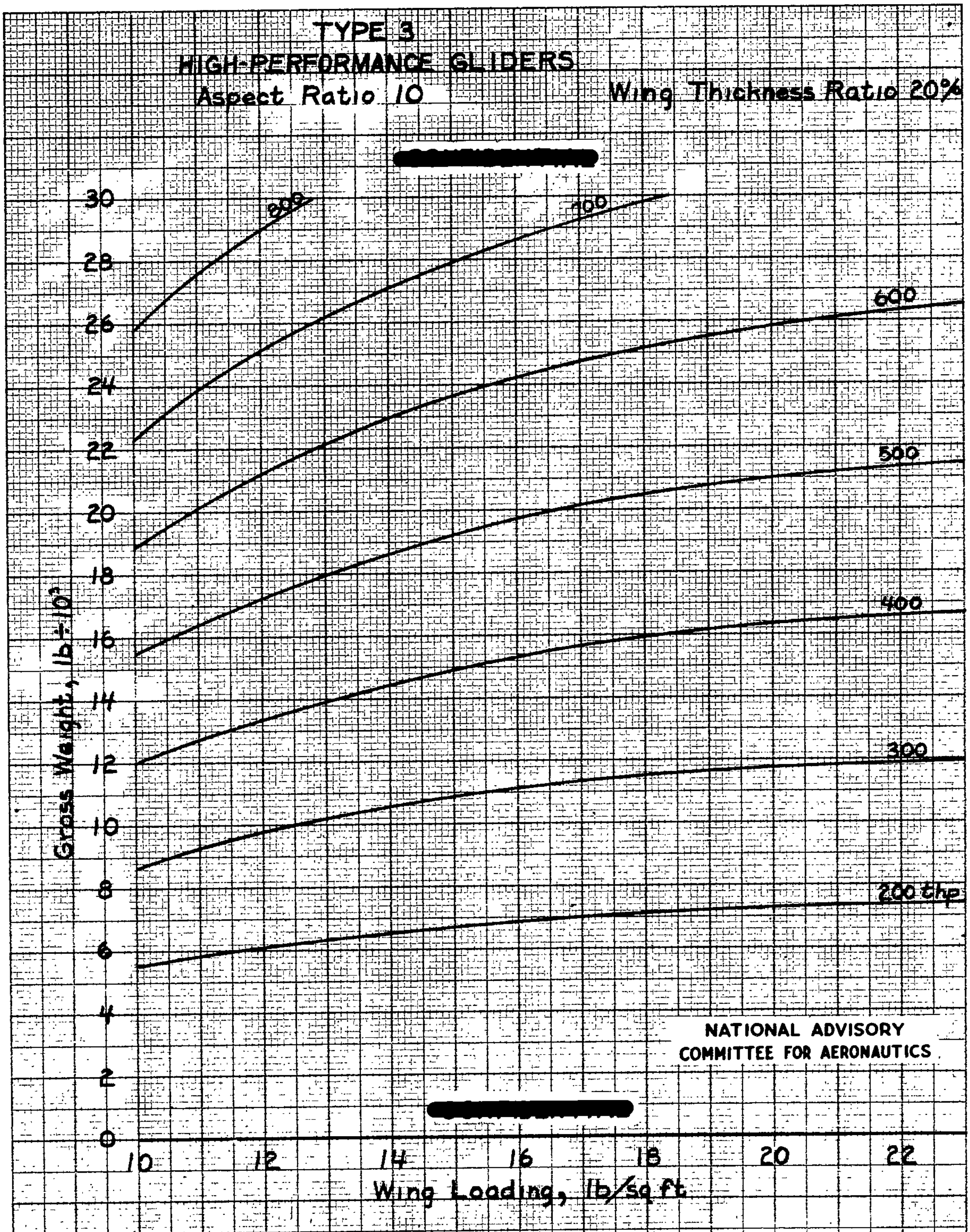

FIGURE 13(d) POWER REQUIRED AT 140 MPH LEVEL

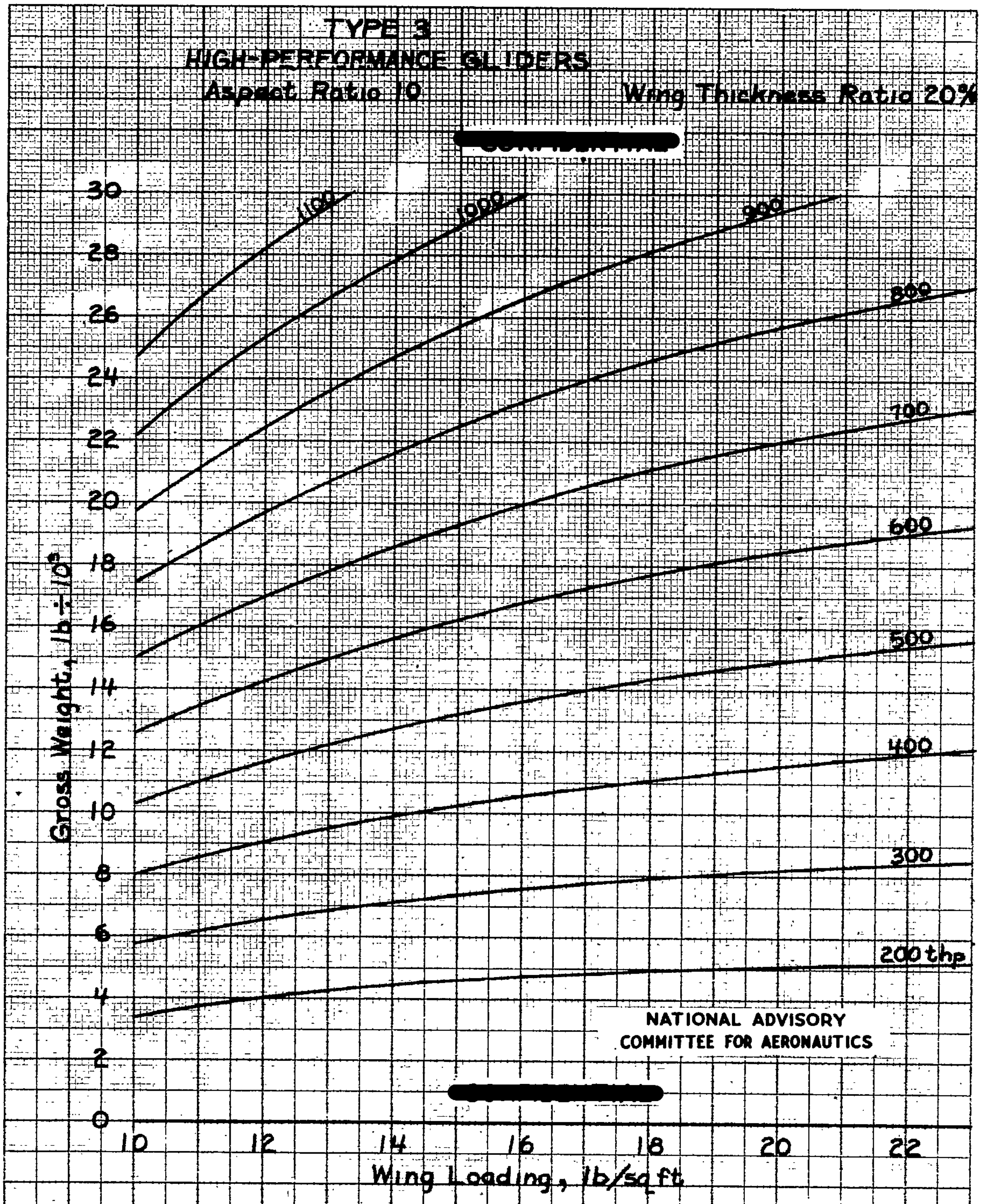

FIGURE 13(e) POWER REQUIRED AT 160 MPH LEVEL

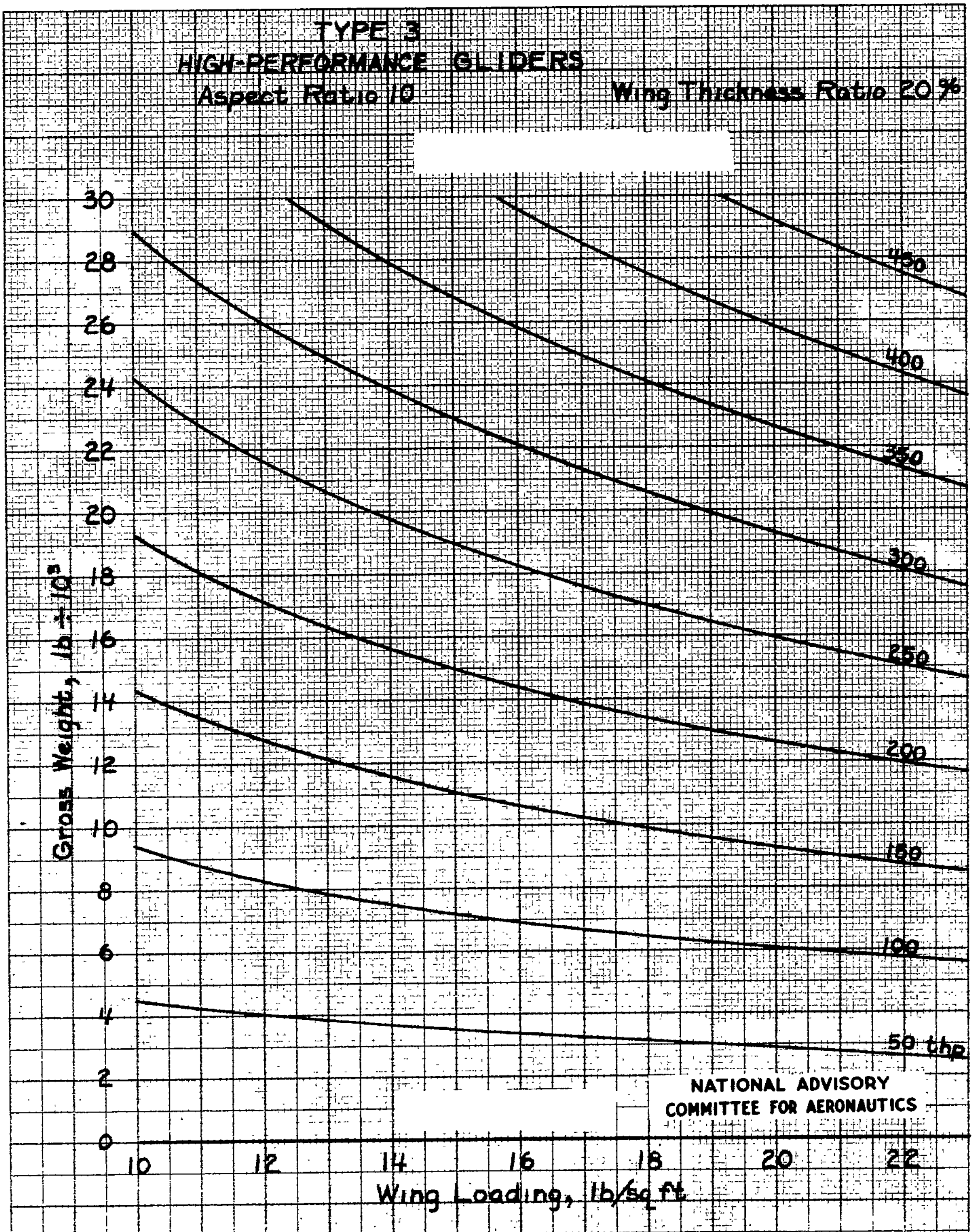

FIGURE 13(f) POWER REQUIRED AT MAXIMUM L/D LEVEL

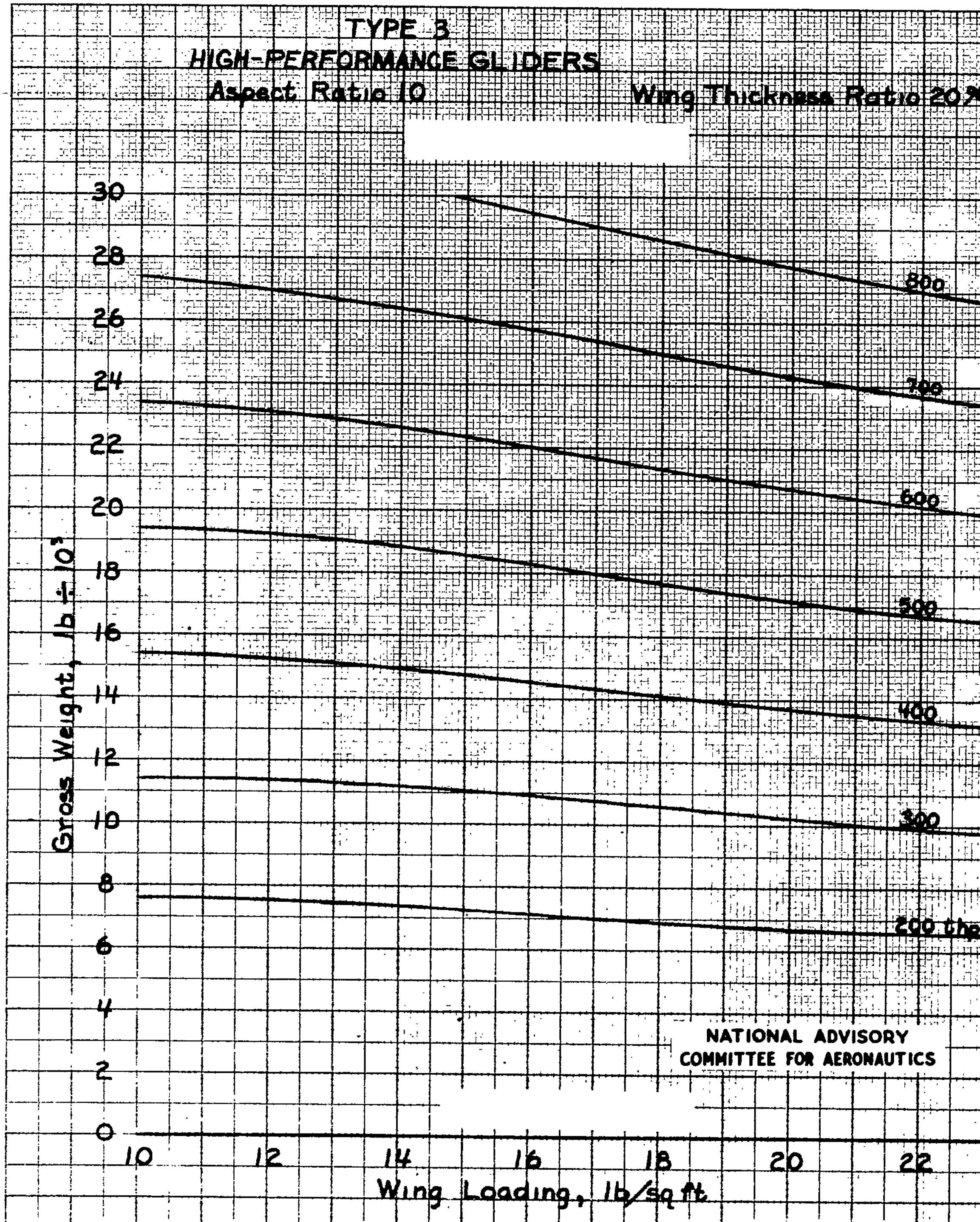

FIGURE 14(a) POWER REQUIRED CLIMBING 500 FT/MIN AT 80 MPH

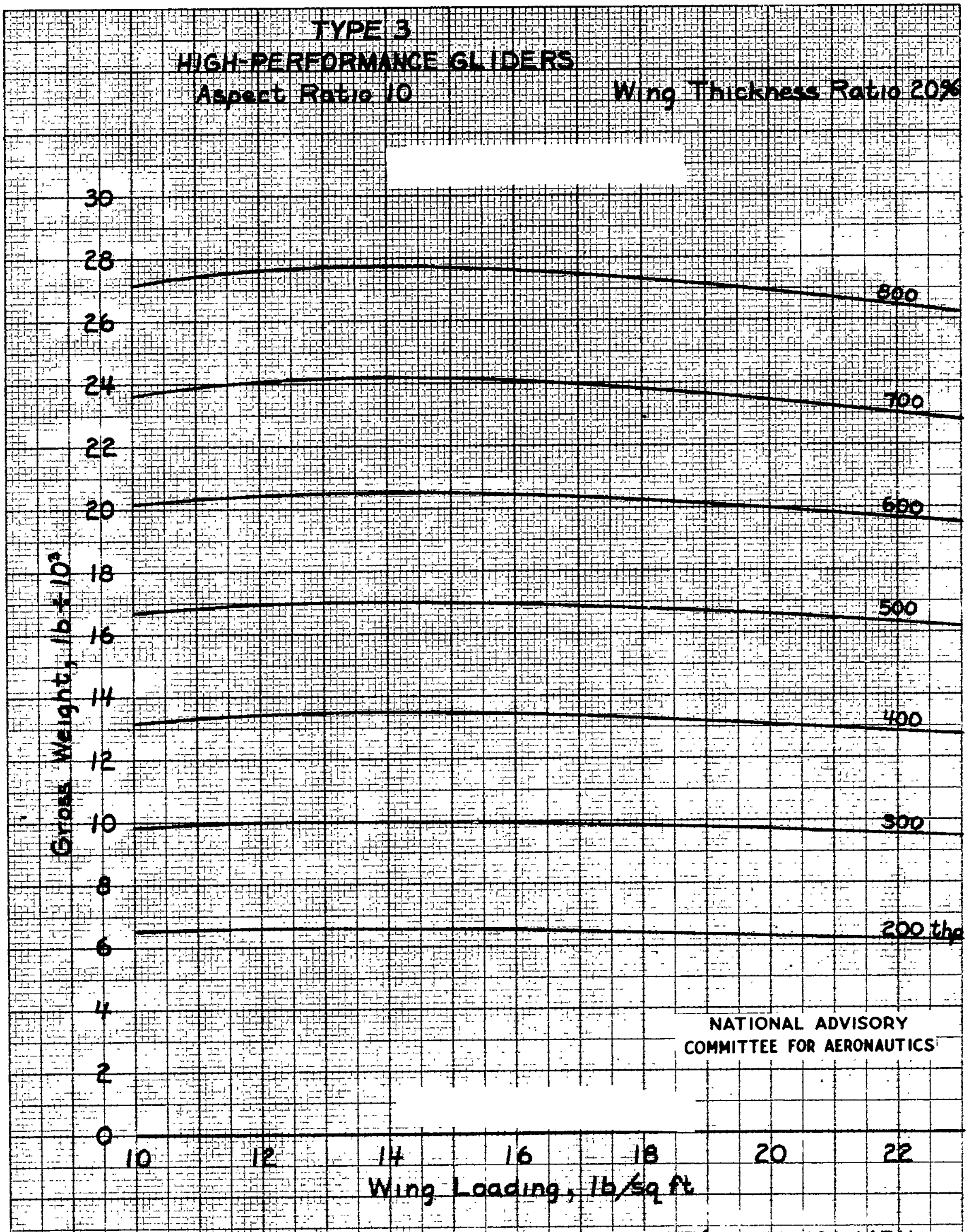

FIGURE 14(b) POWER REQUIRED CLIMBING 500 FT/MIN AT 100 MPH

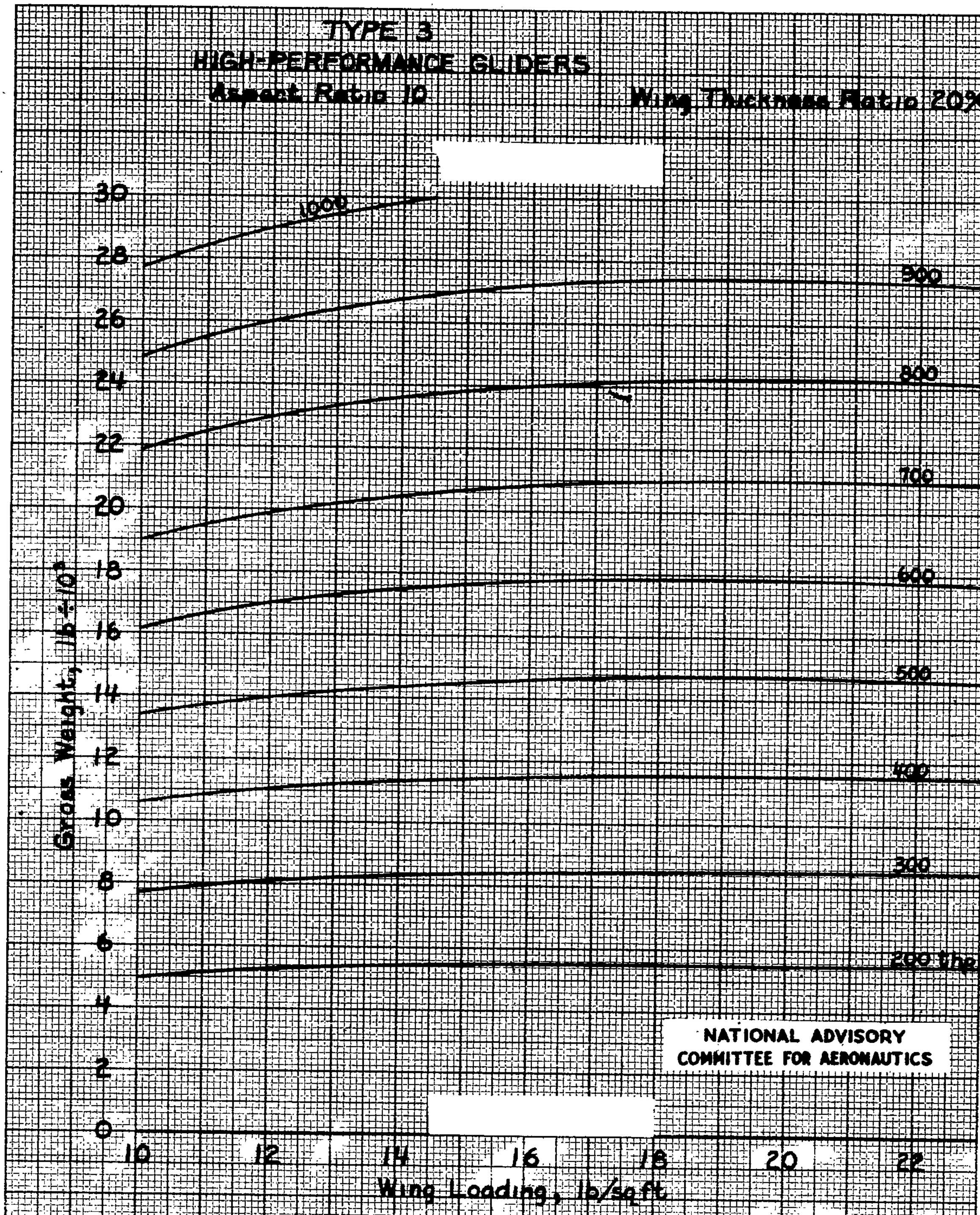

FIGURE 14(c) POWER REQUIRED CLIMBING 500 FT/MIN AT 120 MPH

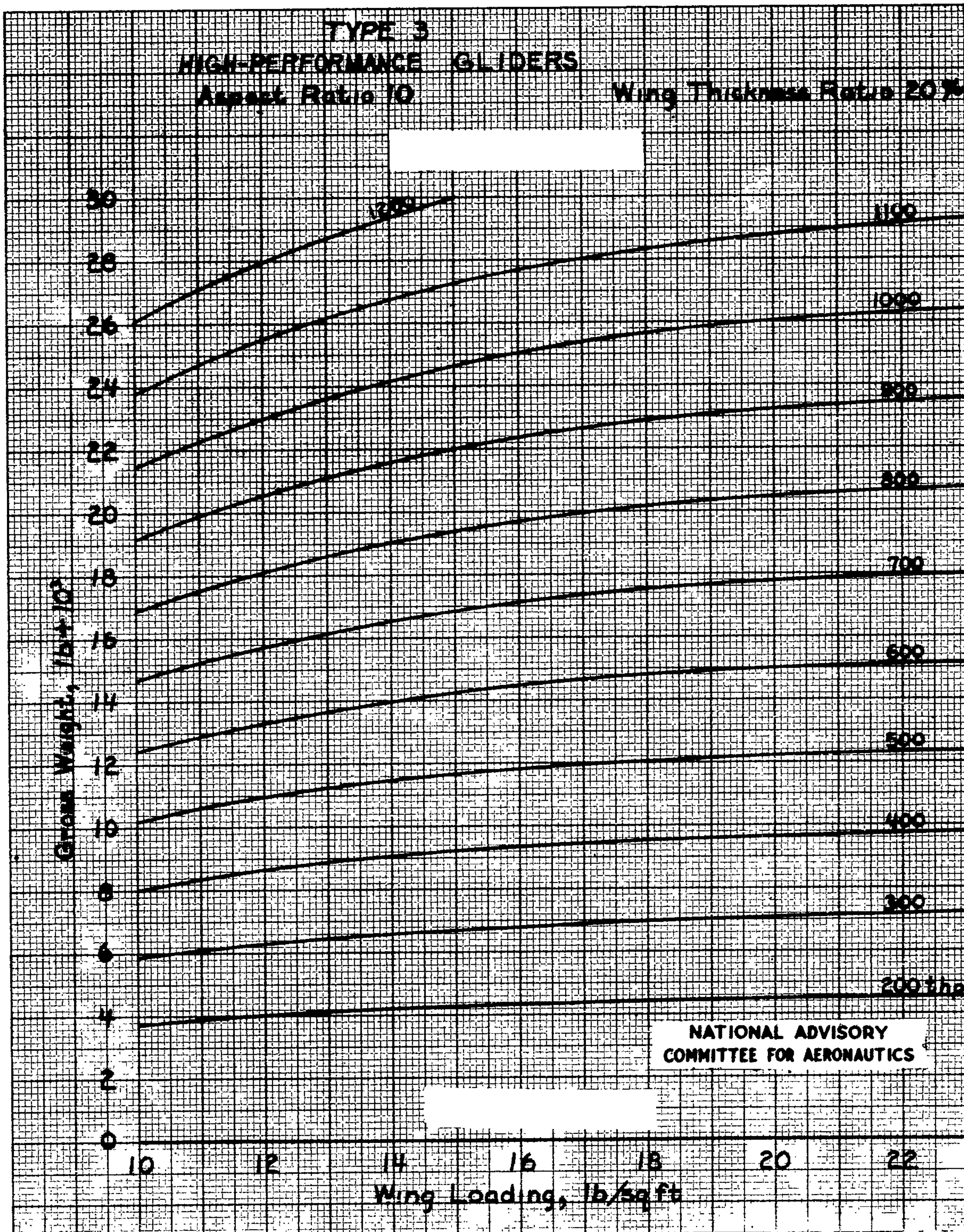

FIGURE 14(d) POWER REQUIRED CLIMBING 500 FT/MIN AT 140 MPH

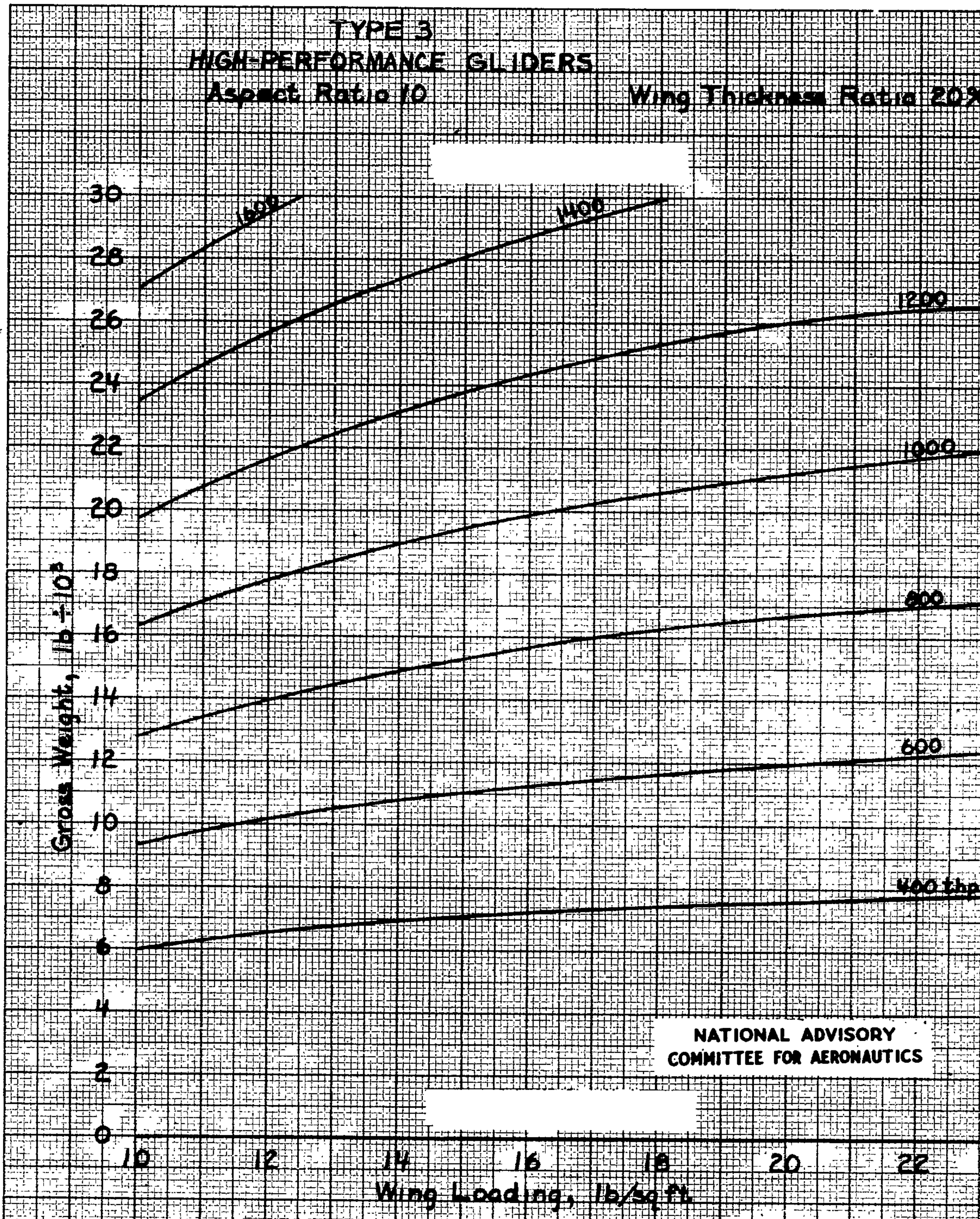

FIGURE 14(a) POWER REQUIRED CLIMBING 500 FT/MIN AT 160 MPH

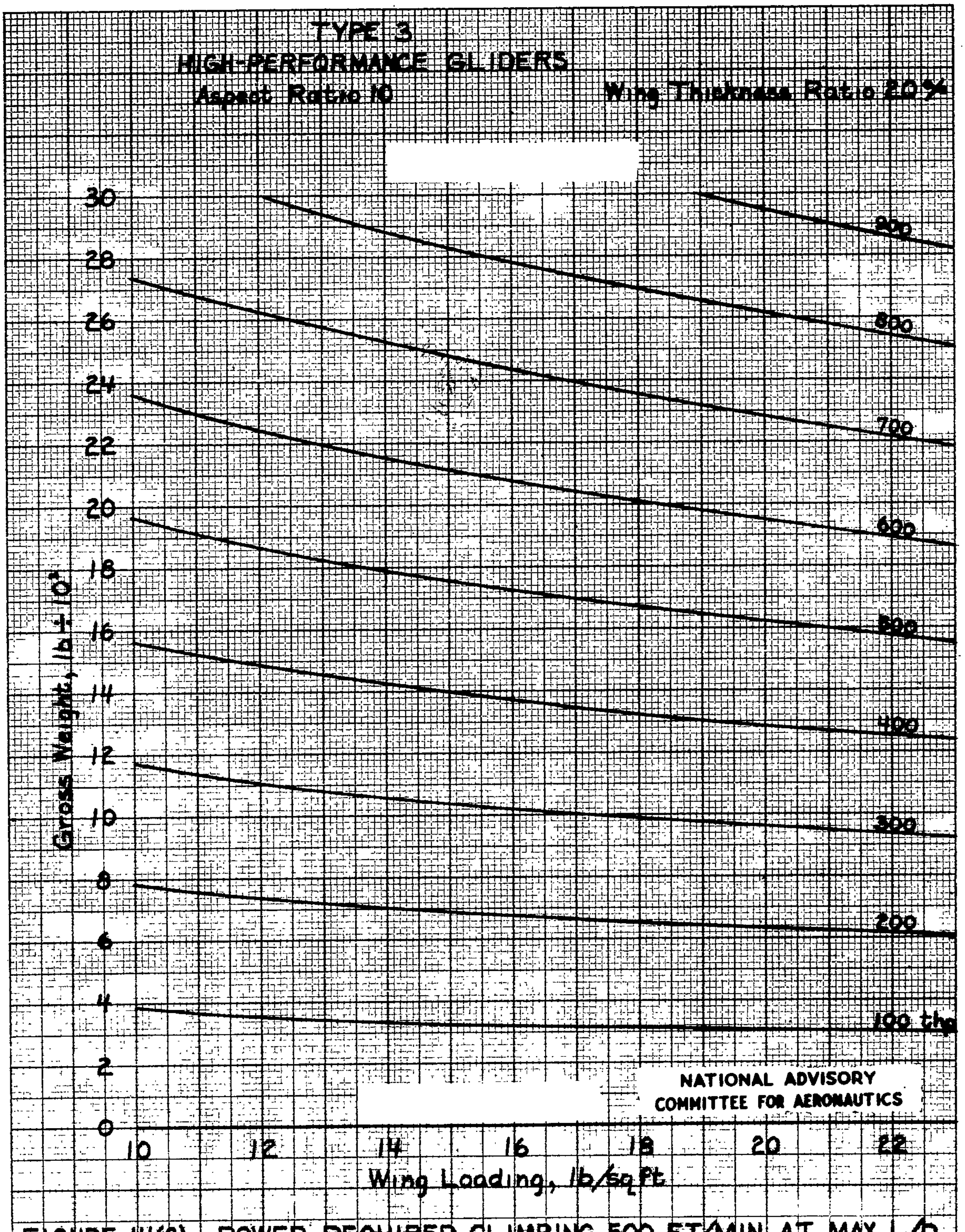

FIGURE 14(f) POWER REQUIRED CLIMBING 500 FT/MIN AT MAX L/D

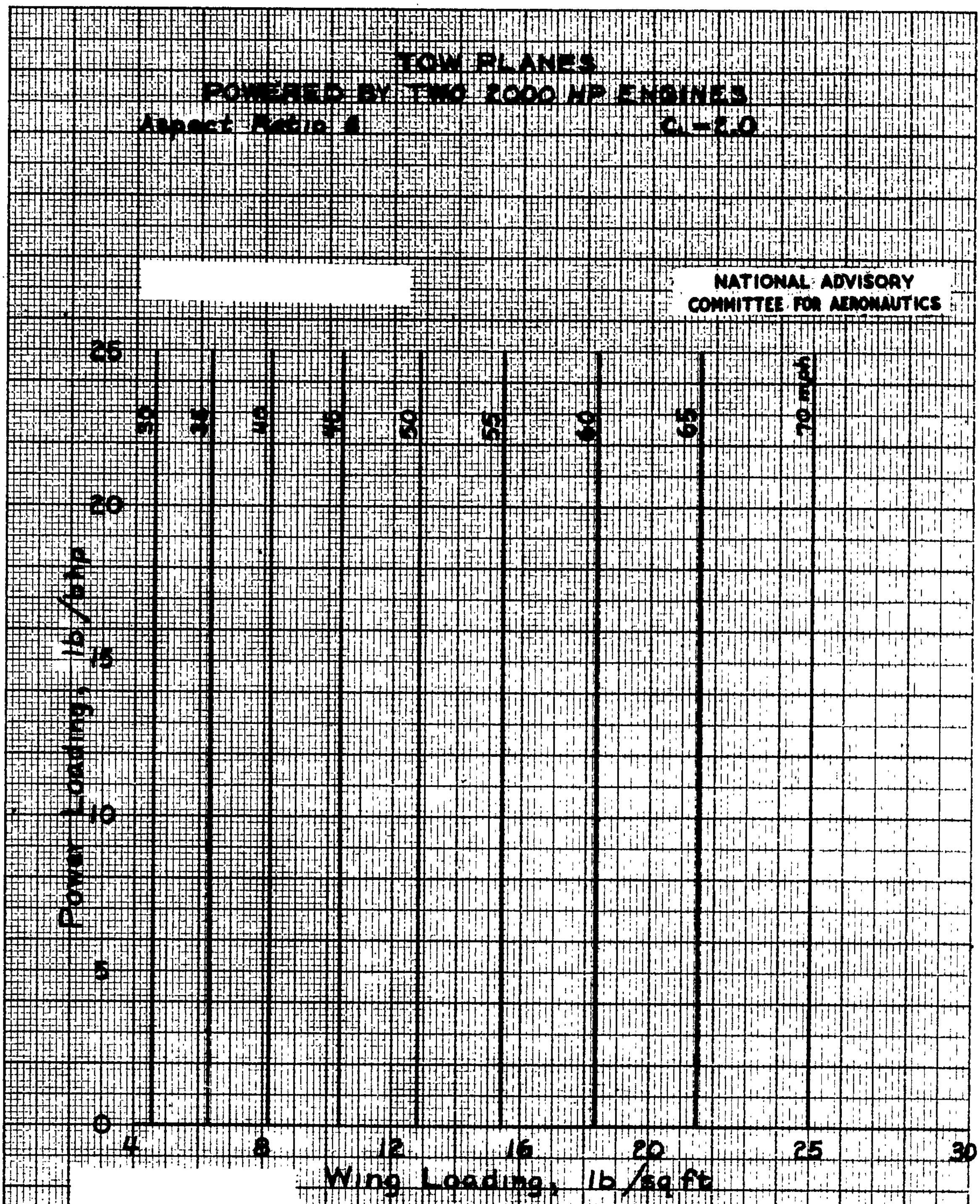

FIGURE 15(a) STALLING SPEEDS WITH FLAPS

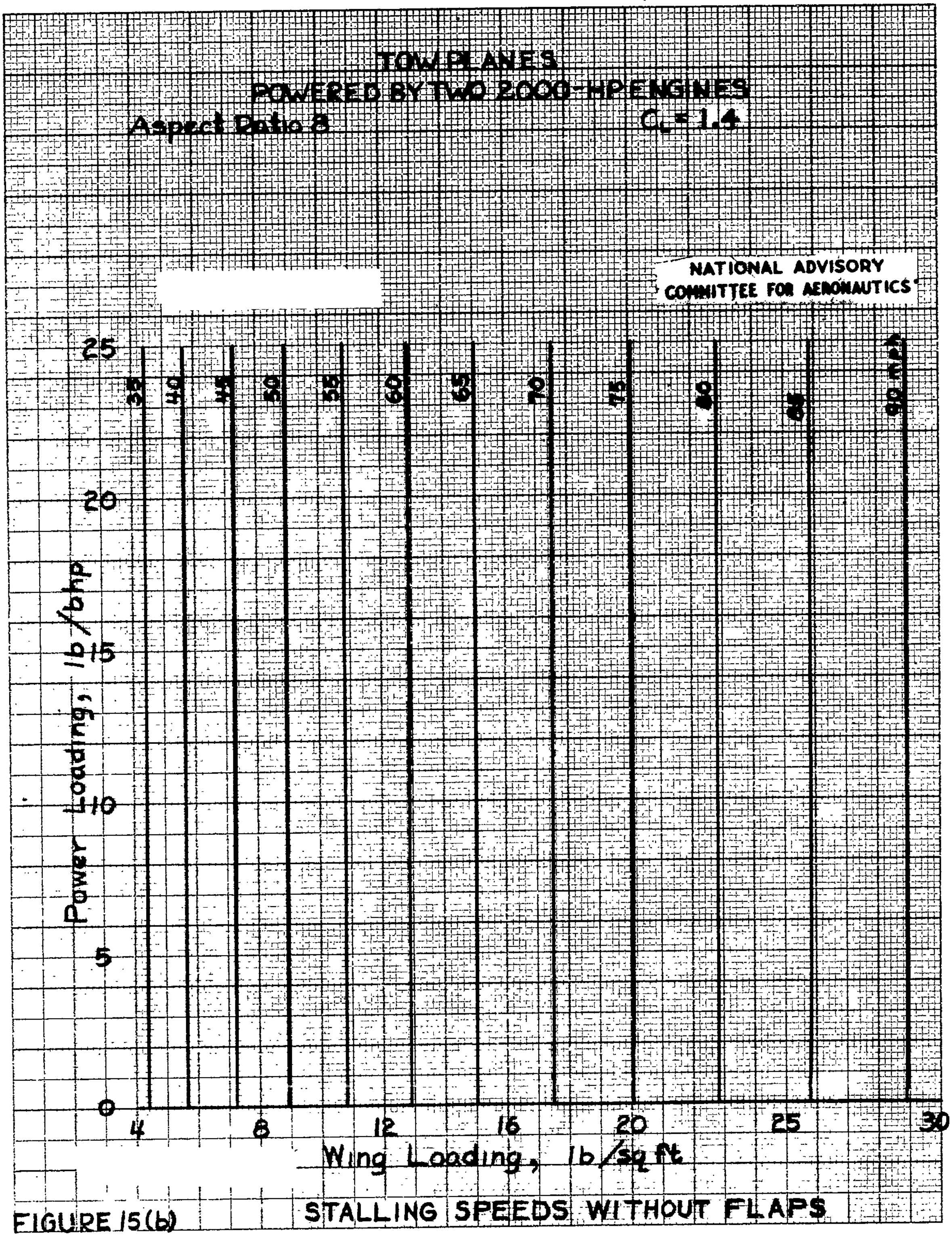

FIGURE 15(b) STALLING SPEEDS WITHOUT FLAPS

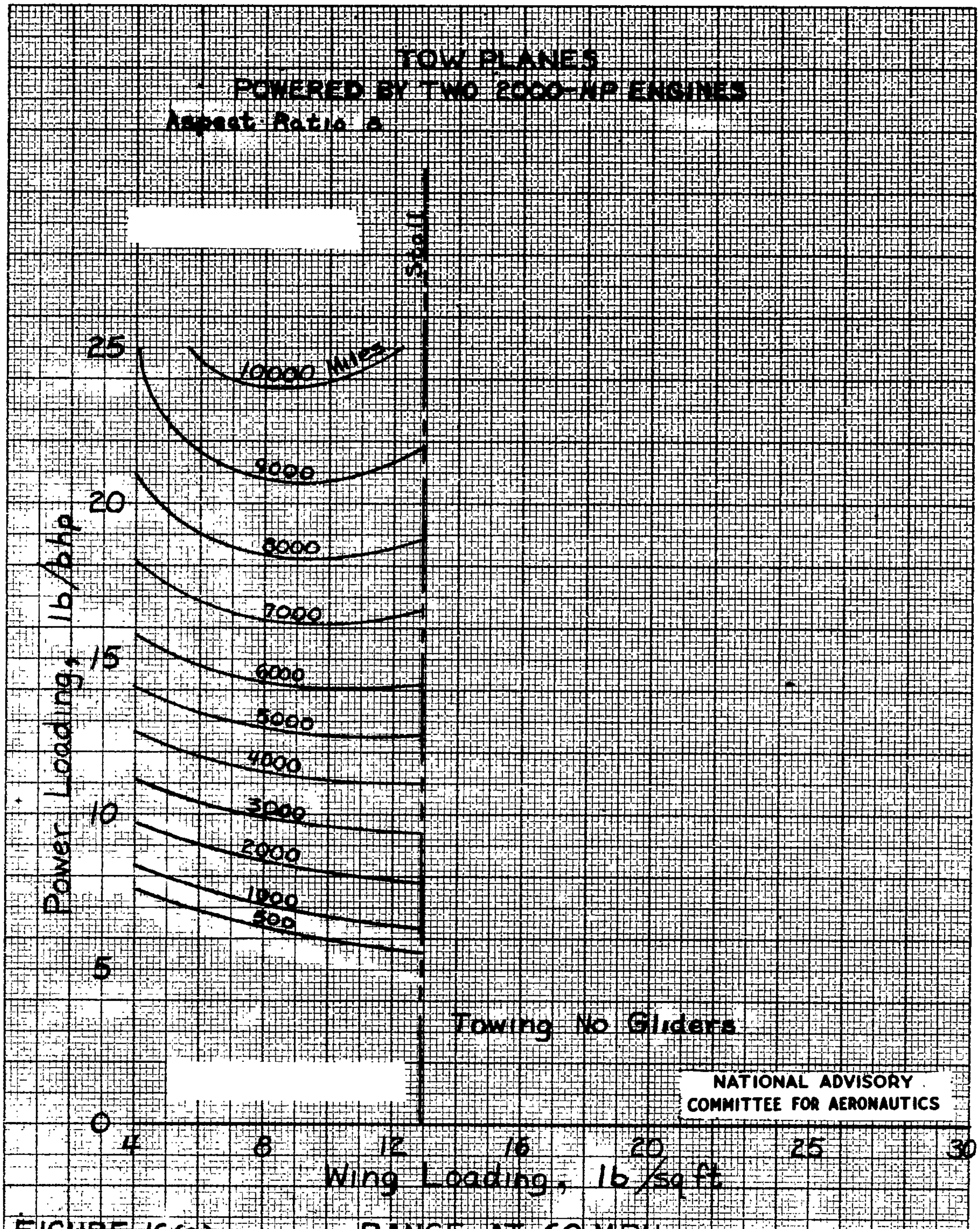

FIGURE 16(a) RANGE AT 60 MPH

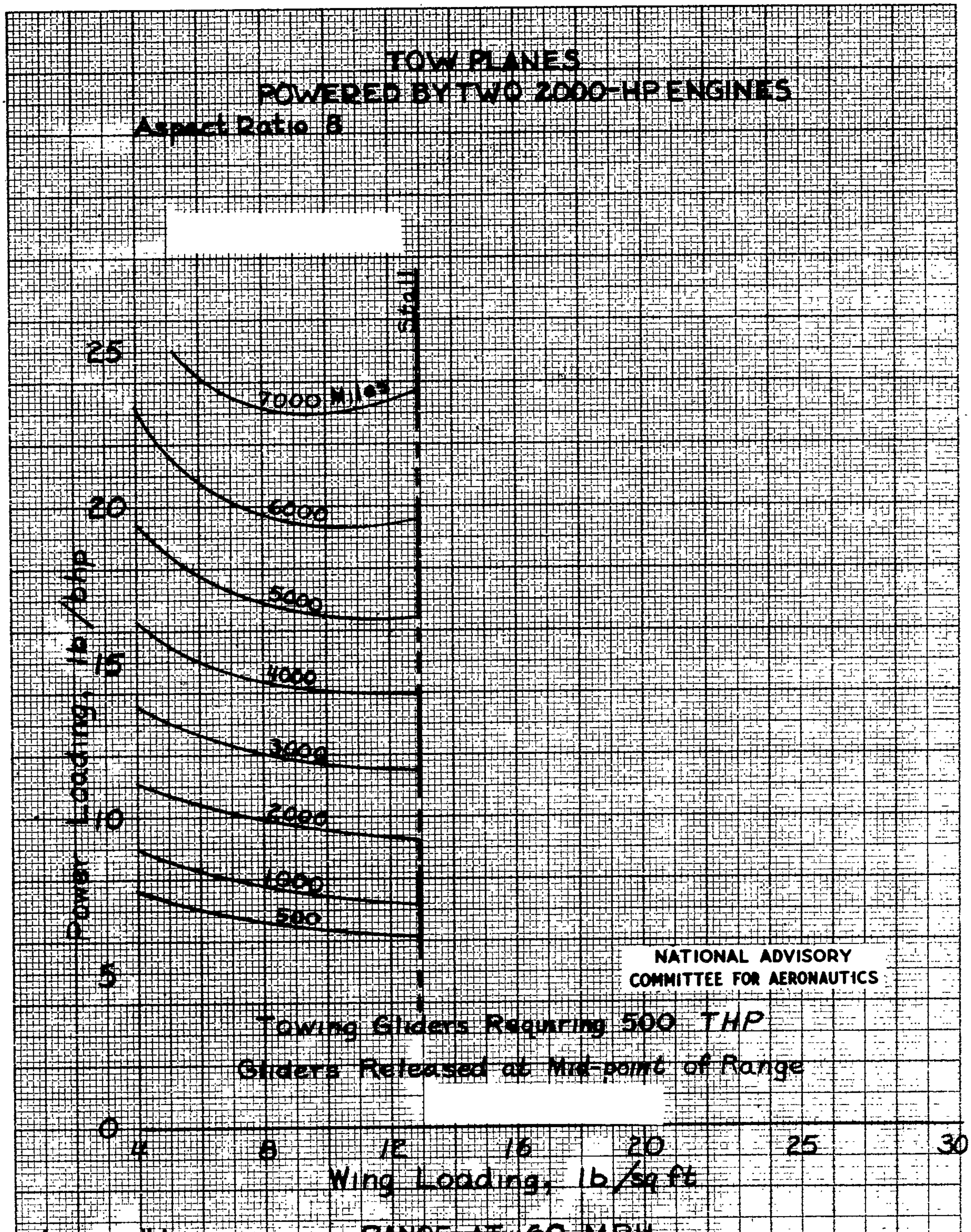

FIGURE 16(b) RANGE AT 60 MPH

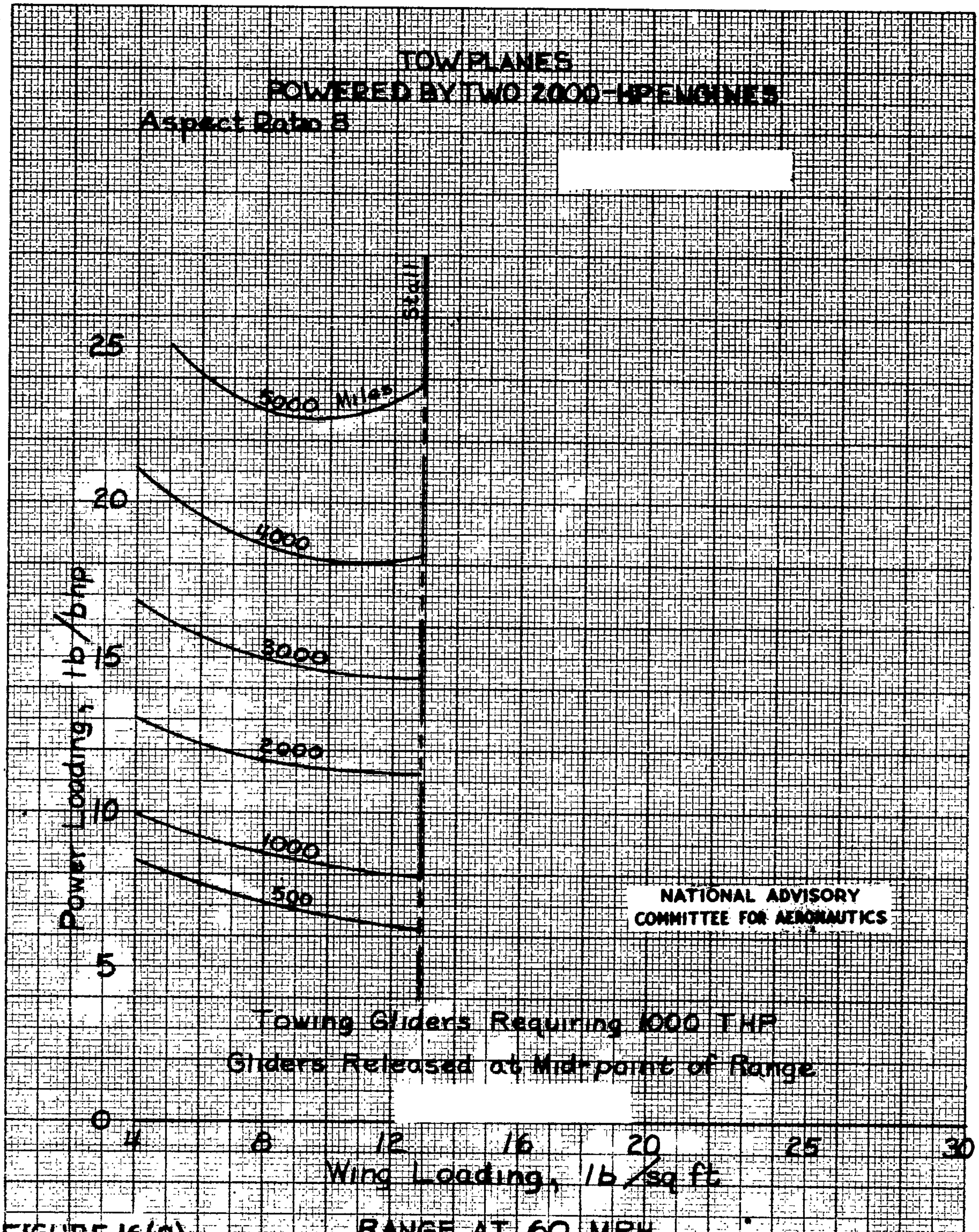

FIGURE 16(c) RANGE AT 60 MPH

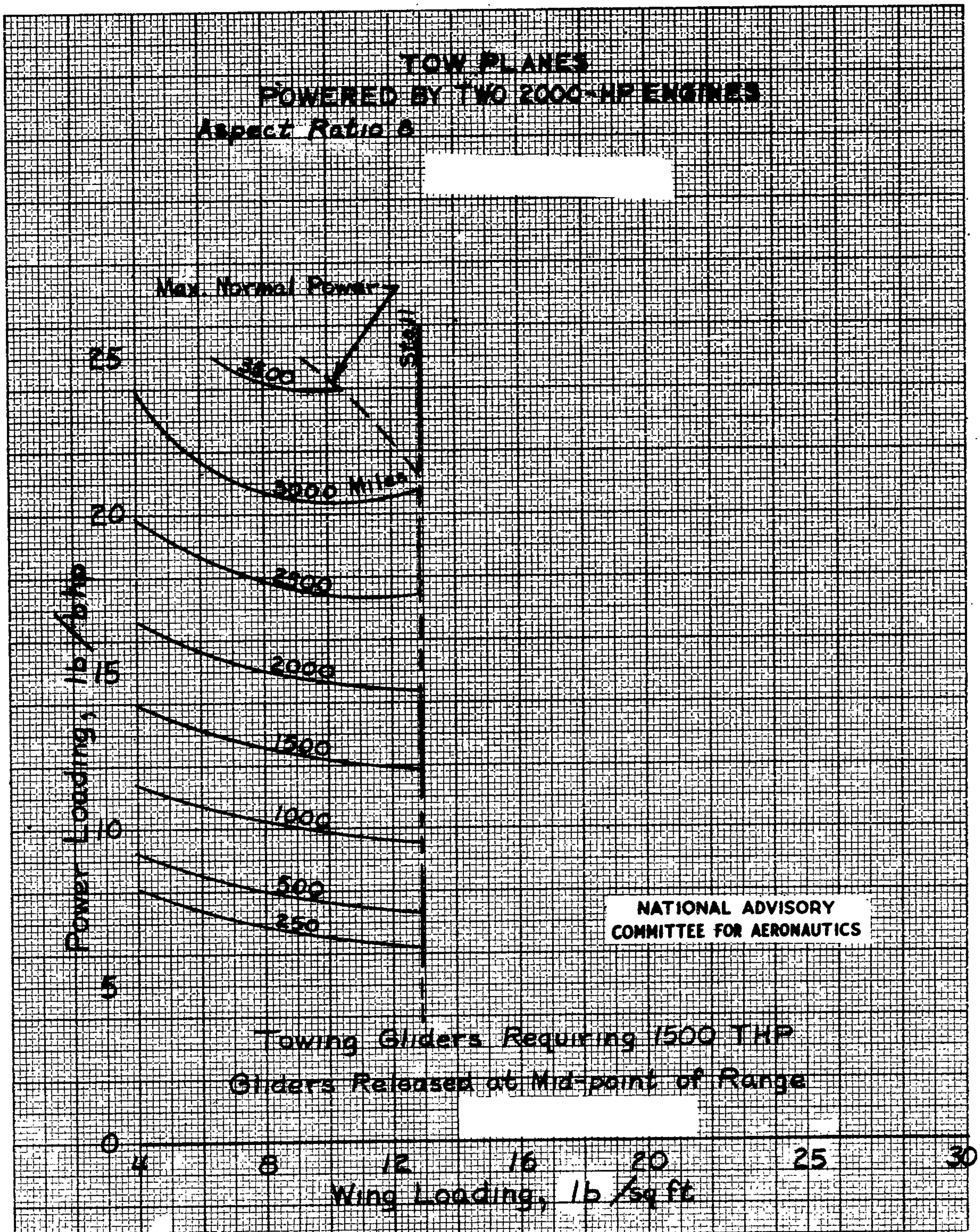

FIGURE 16(d) RANGE AT 60 MPH

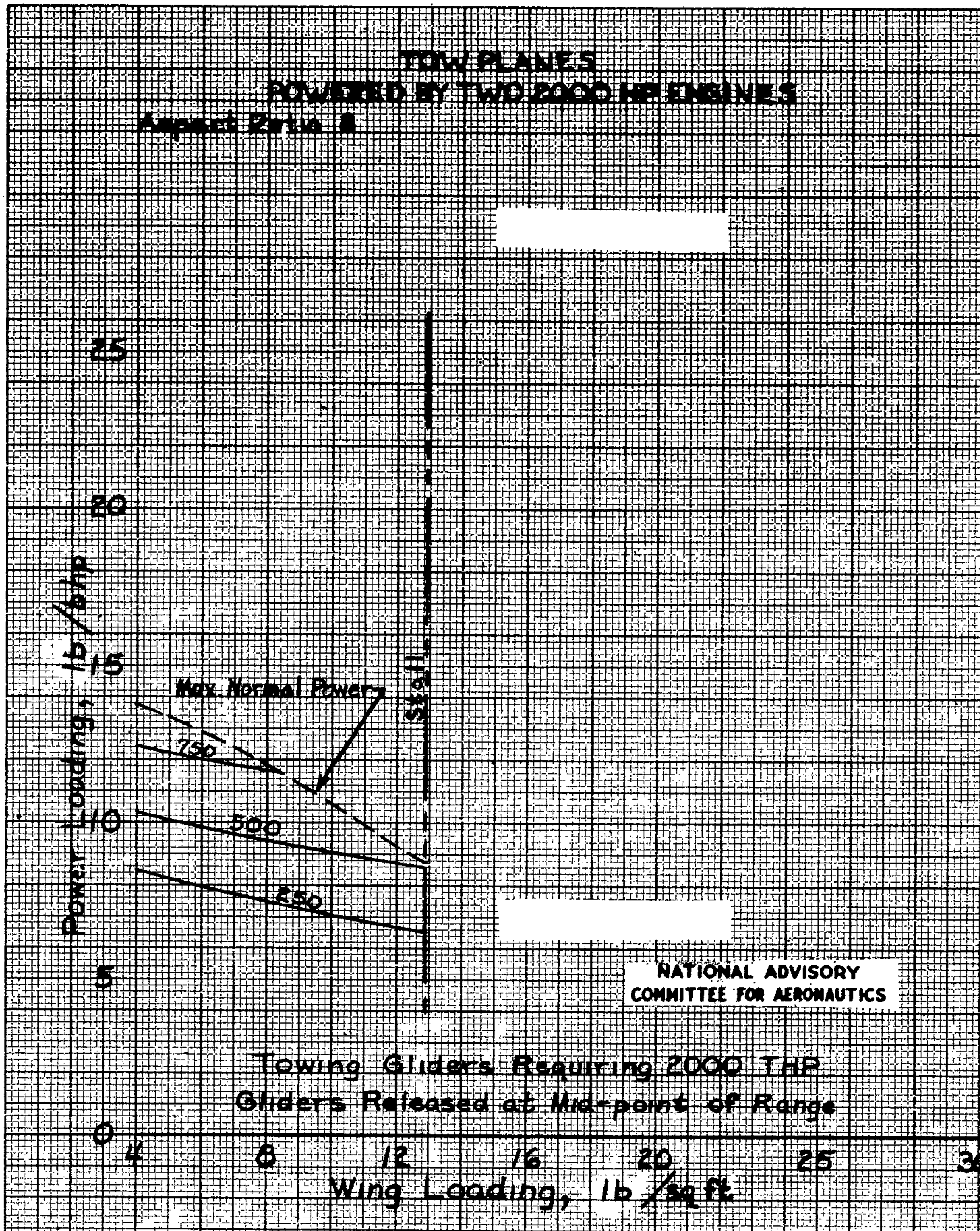

FIGURE 16(e) RANGE AT 60 MPH

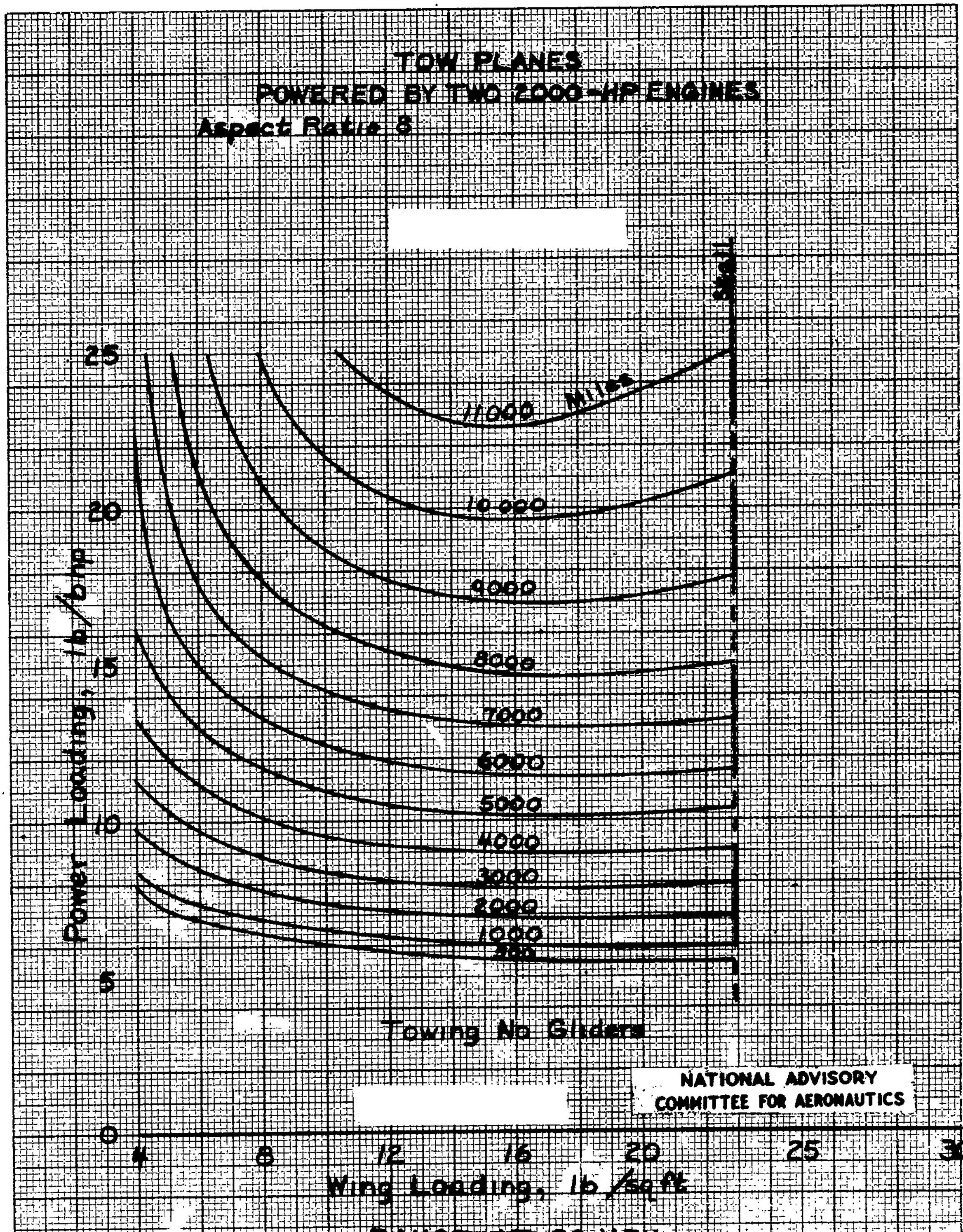

FIGURE 17(a) RANGE AT 80 MPH

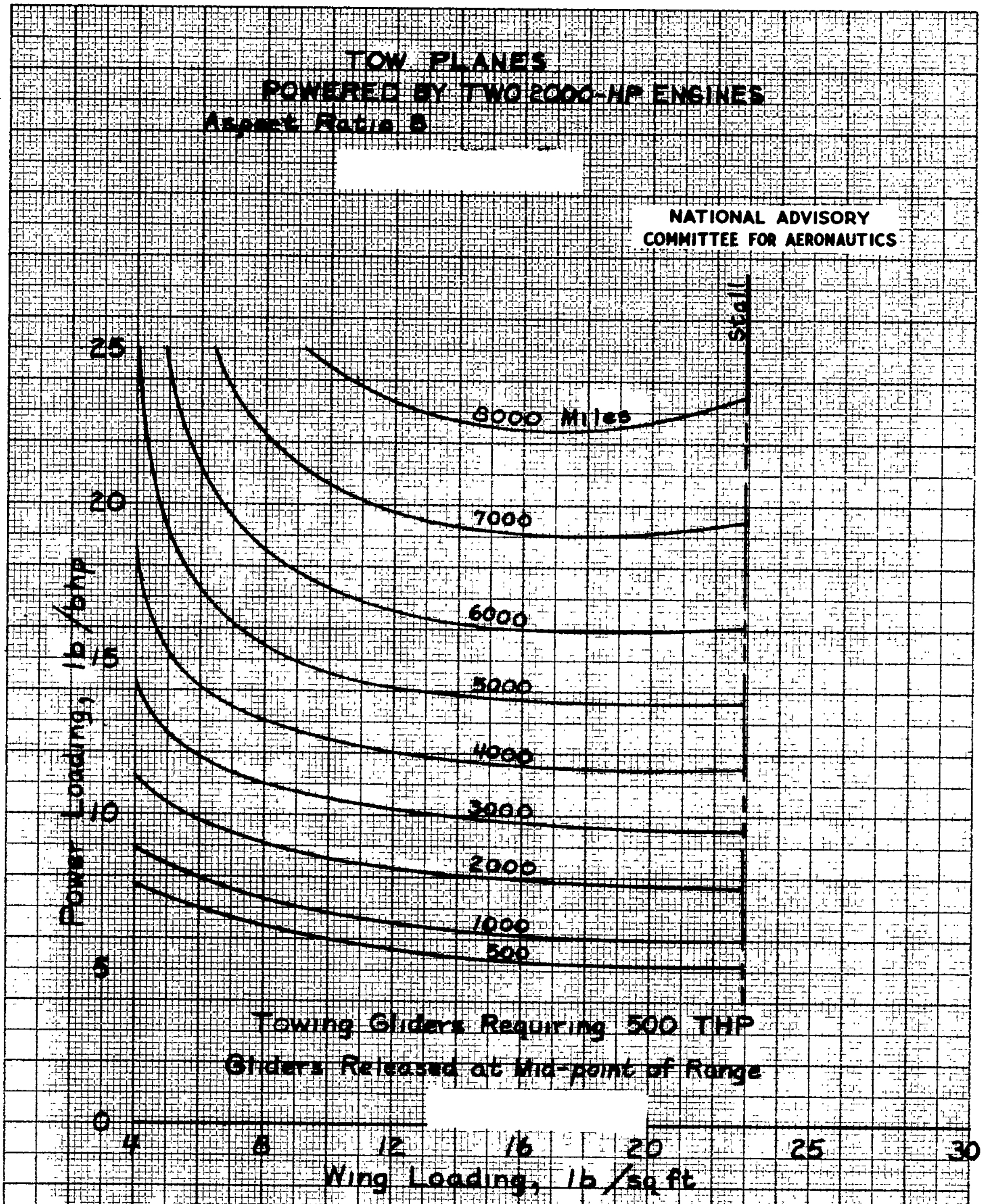

FIGURE 17(b) RANGE AT 80 MPH

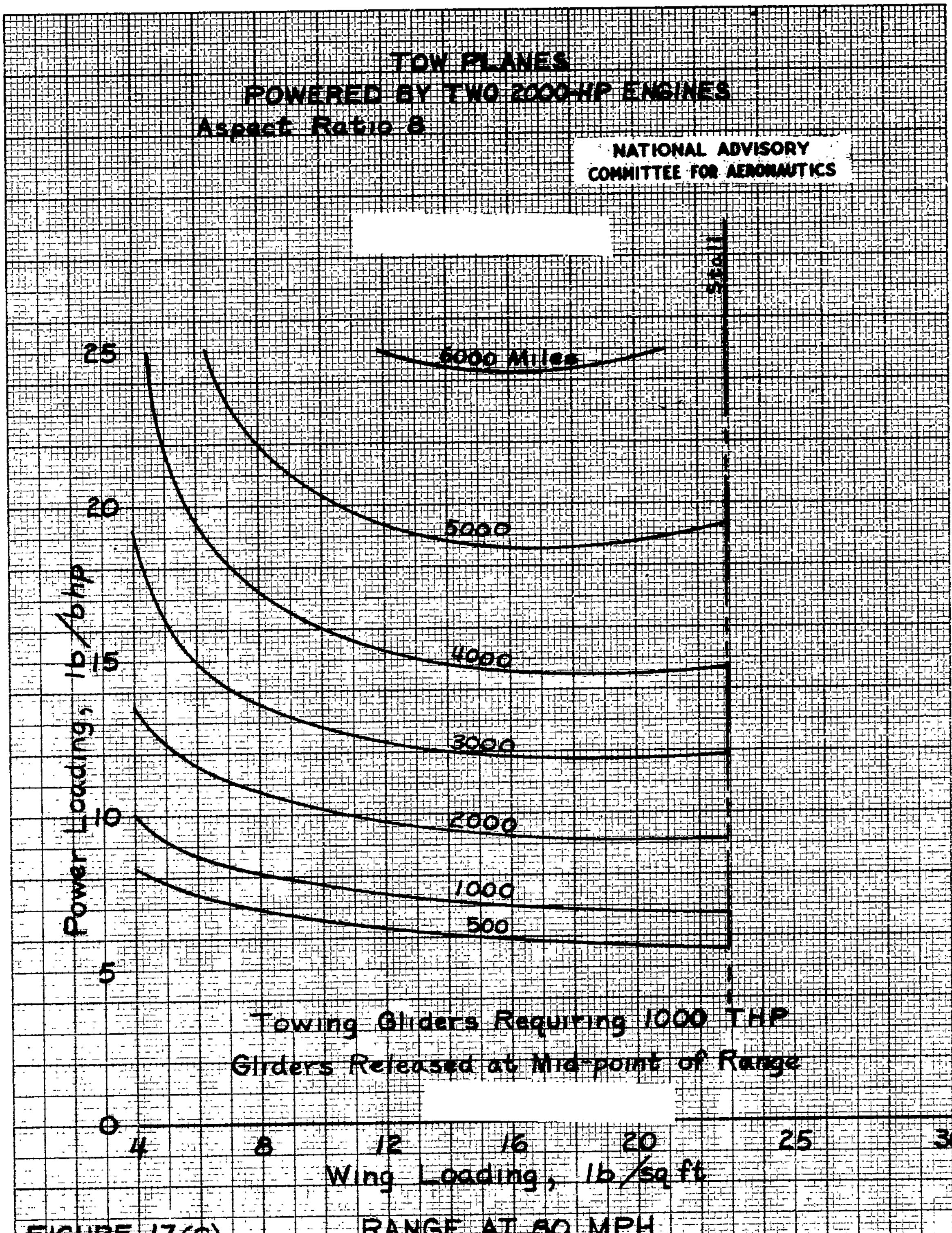

FIGURE 17(c) RANGE AT 80 MPH

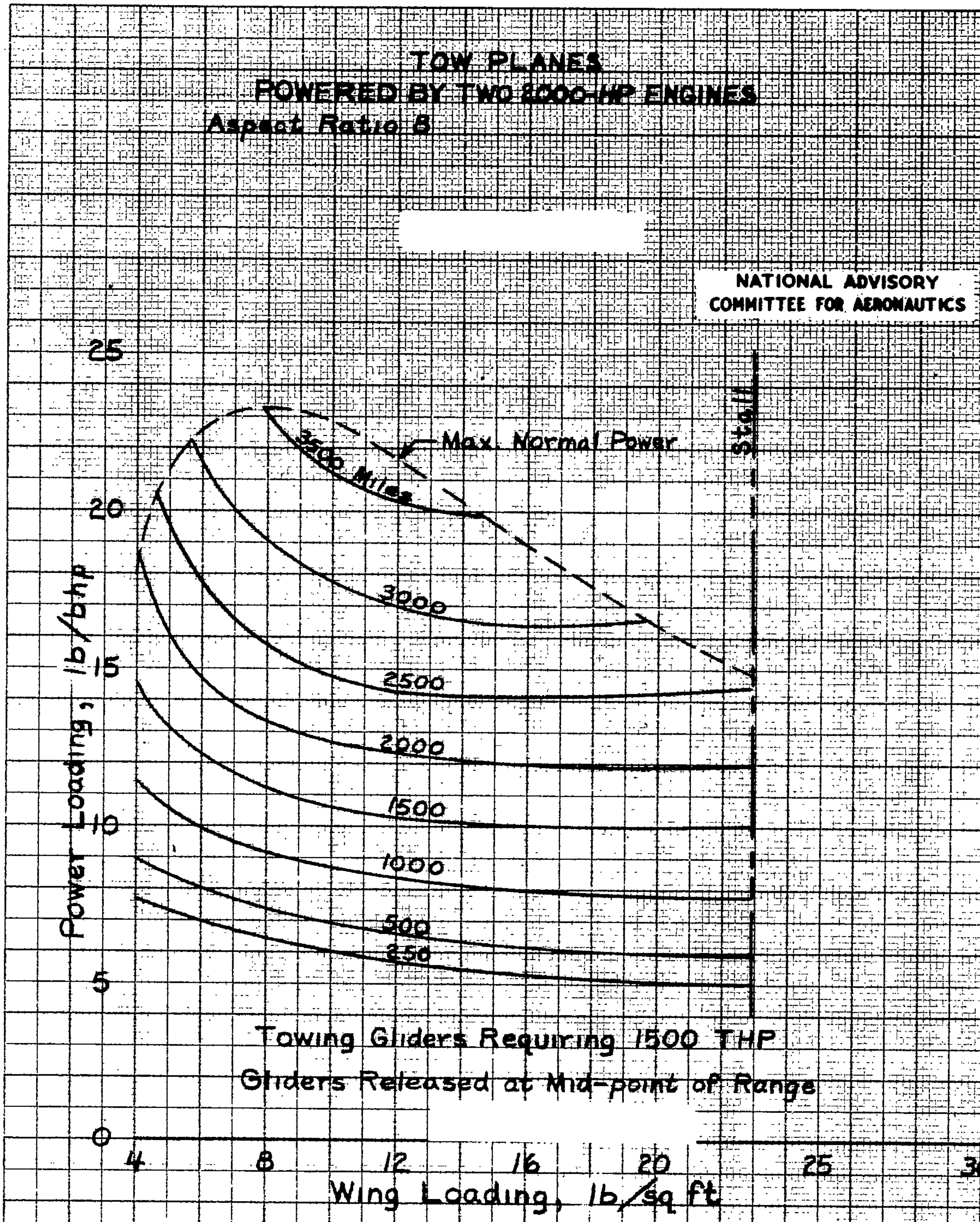

FIGURE 17 (d) RANGE AT 80 MPH

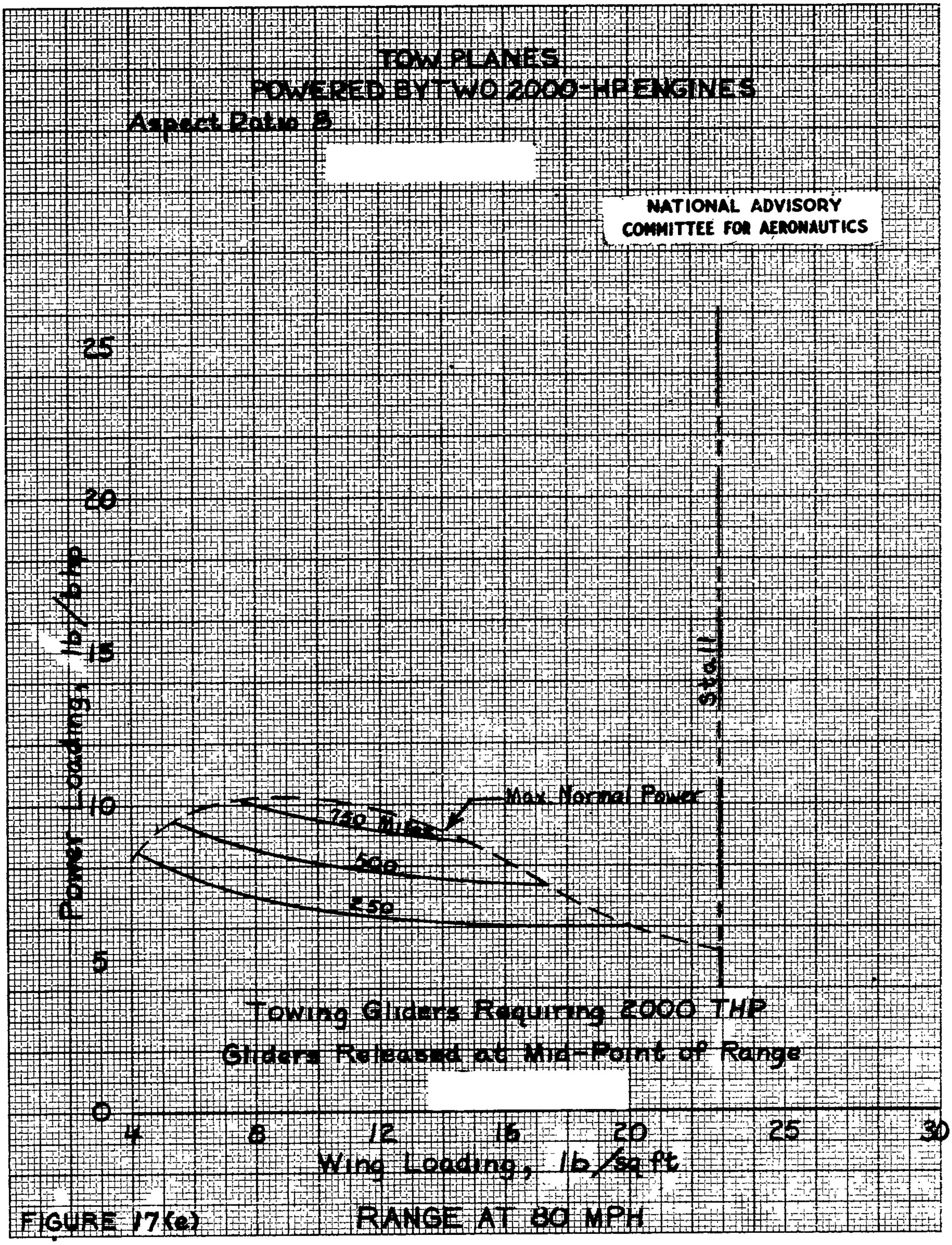

FIGURE 17(e) RANGE AT 80 MPH

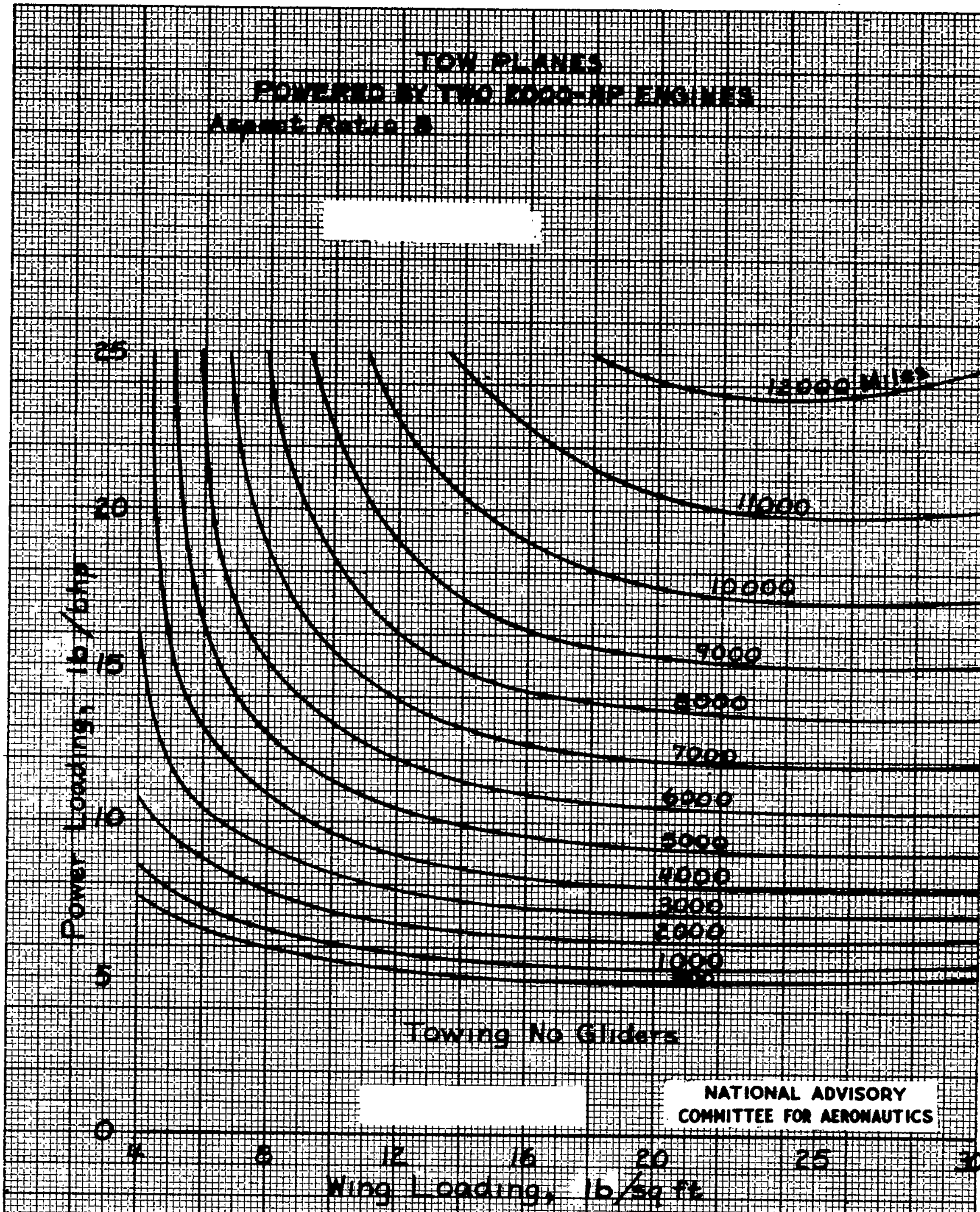

FIGURE 18(a) RANGE AT 100 MPH

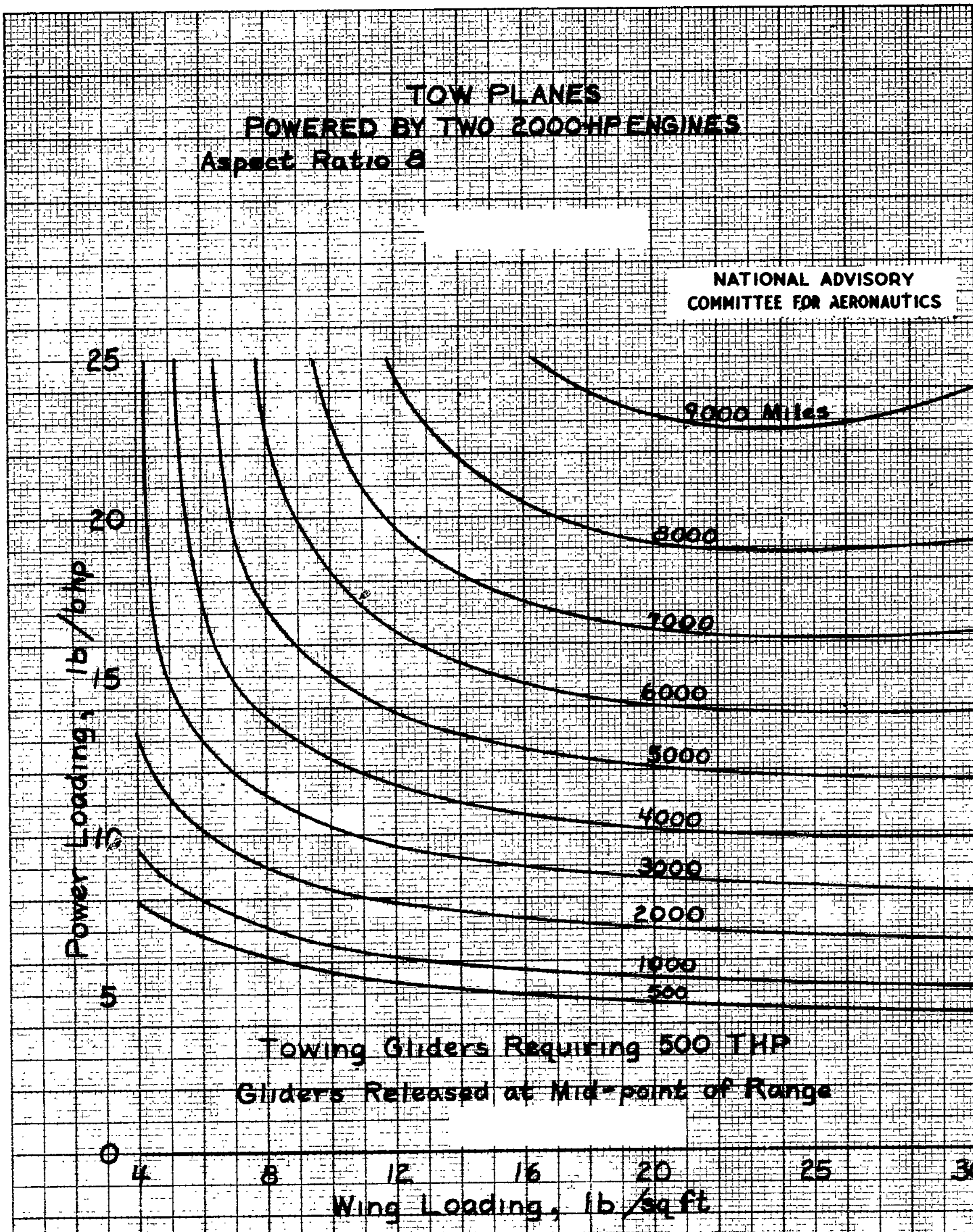

FIGURE 18(b) RANGE AT 100 MPH

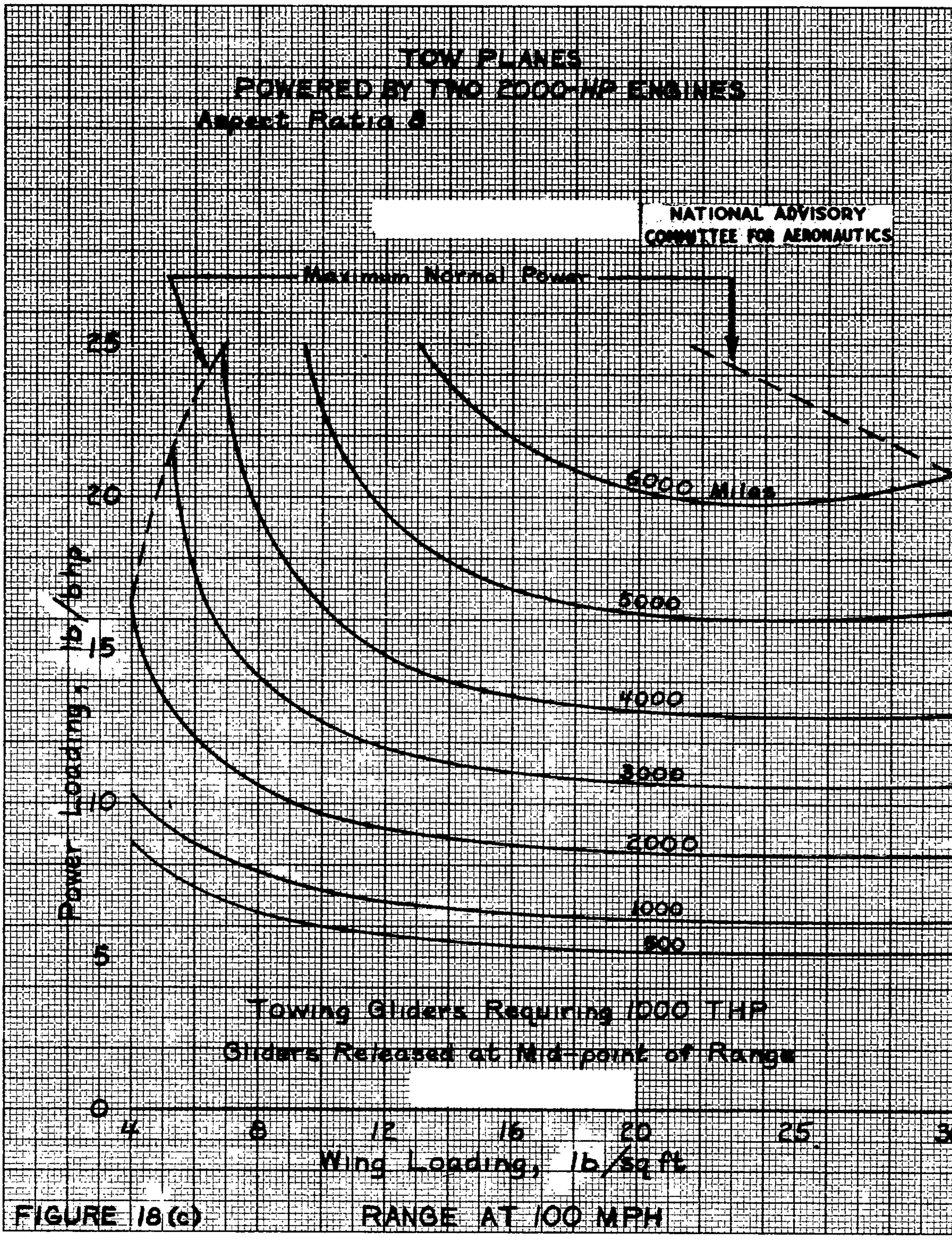

FIGURE 18(c) RANGE AT 100 MPH

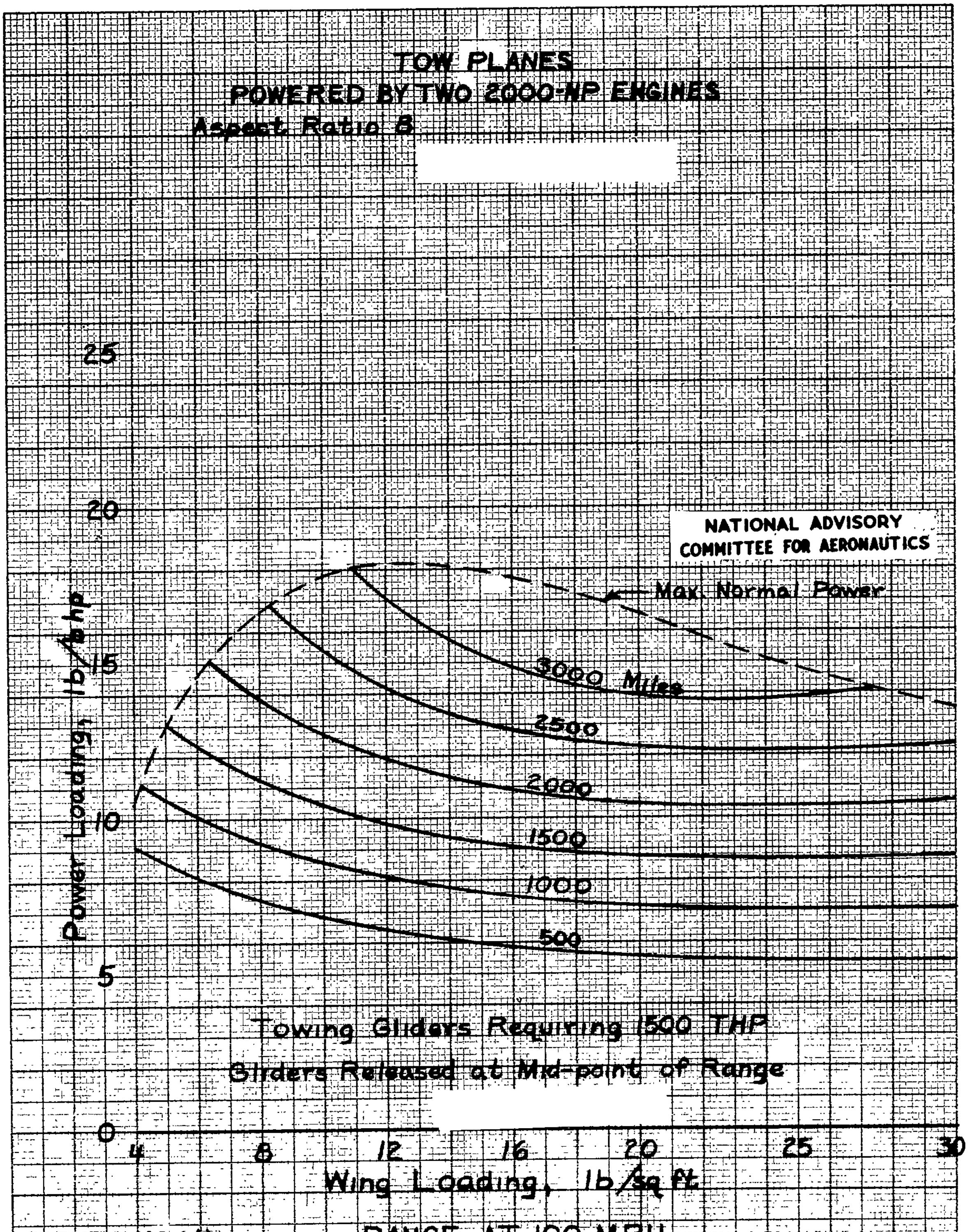
TOW PLANES
POWERED BY TWO 2000-HP ENGINES
Aspect Ratio 8
NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS
Max. Normal Power
3000 Miles
2500
2000
1500
1000
500
Power Loading, lb/bhp
25
20
15
10
5
0
4
8
12
16
20
25
30
Wing Loading, lb/sq ft
Towing Gliders Requiring 1500 THP
Gliders Released at Mid-point of Range
RANGE AT 100 MPH

FIGURE 18(d)

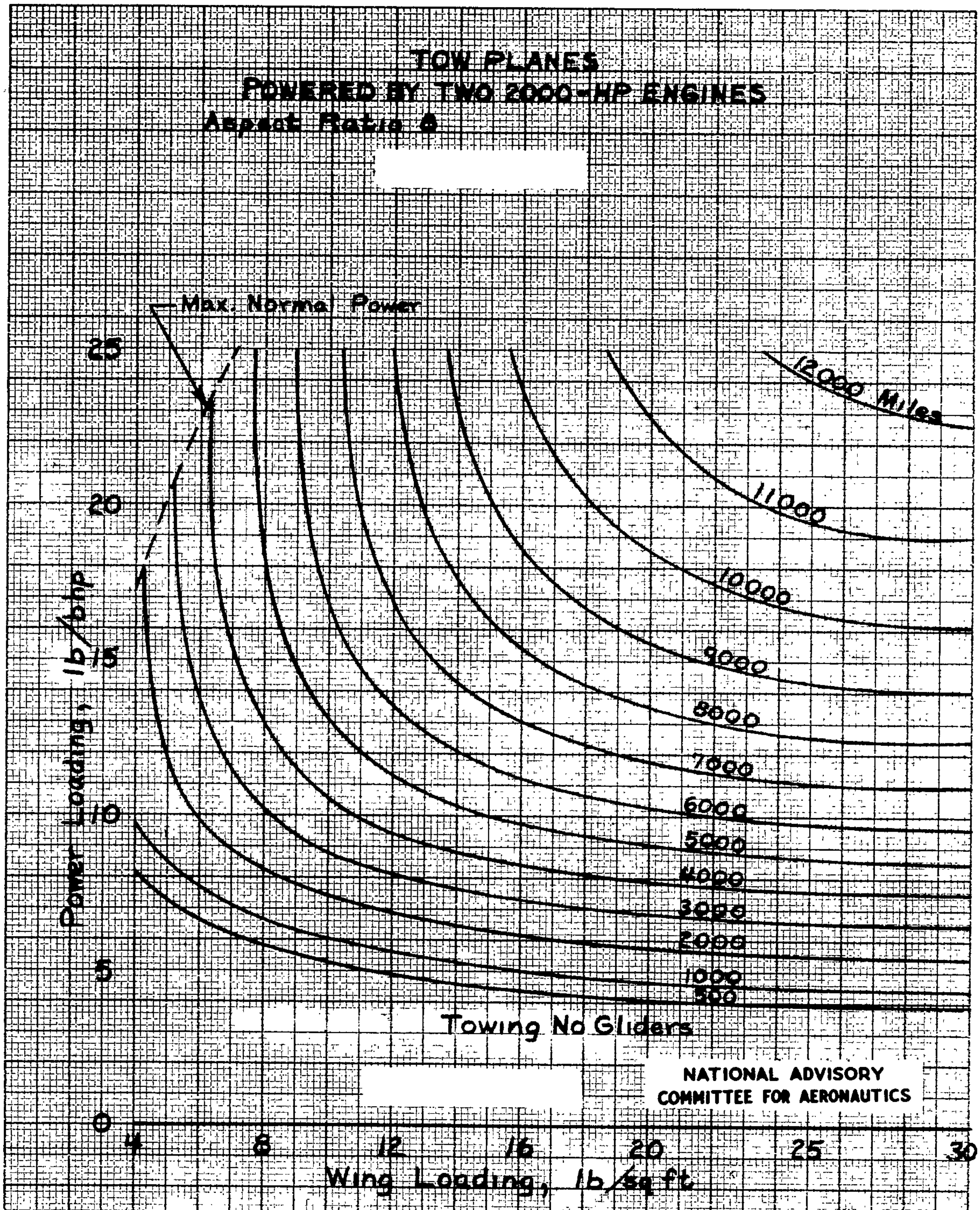

FIGURE 19 (a) RANGE AT 120 MPH

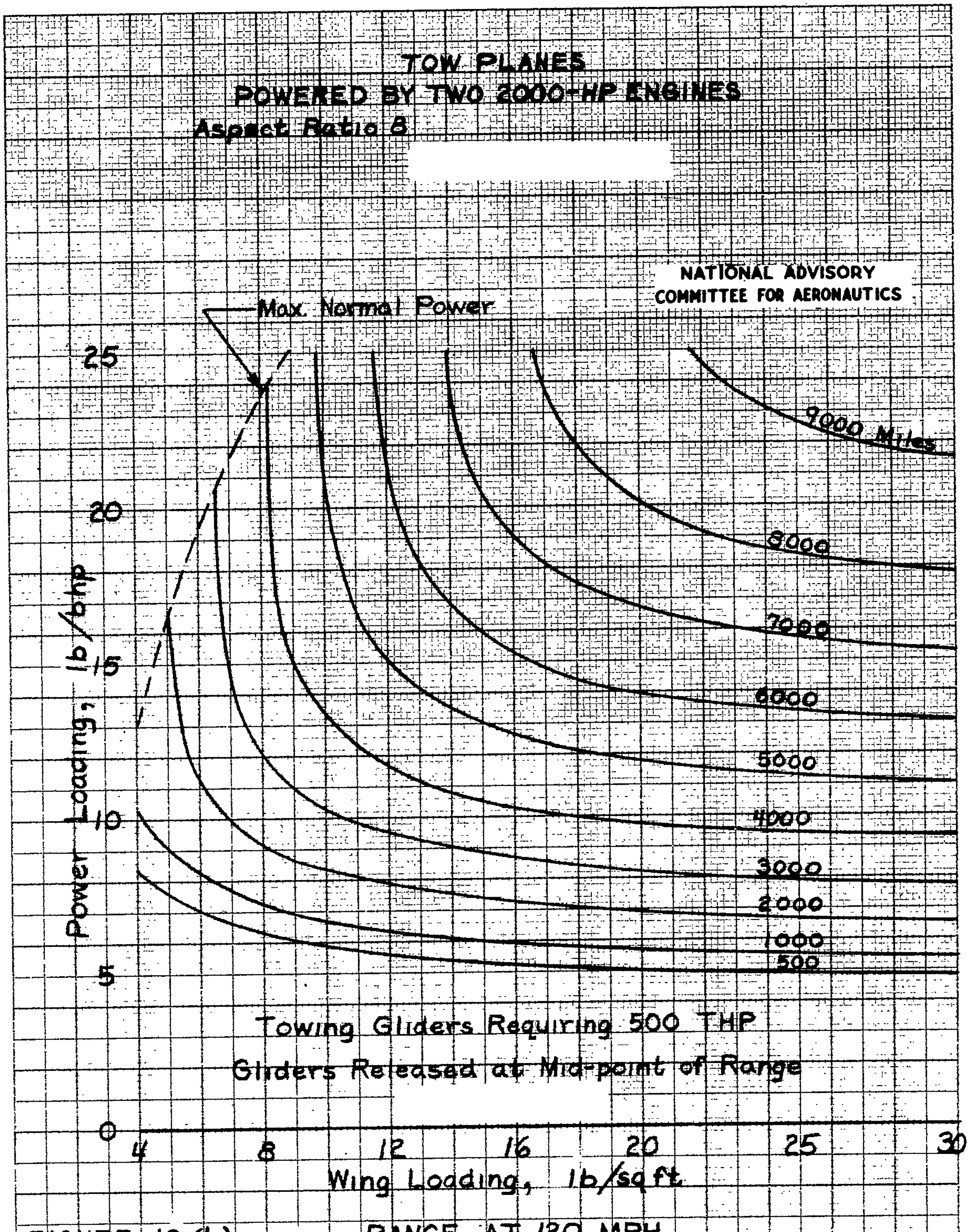

FIGURE 19 (b) RANGE AT 120 MPH

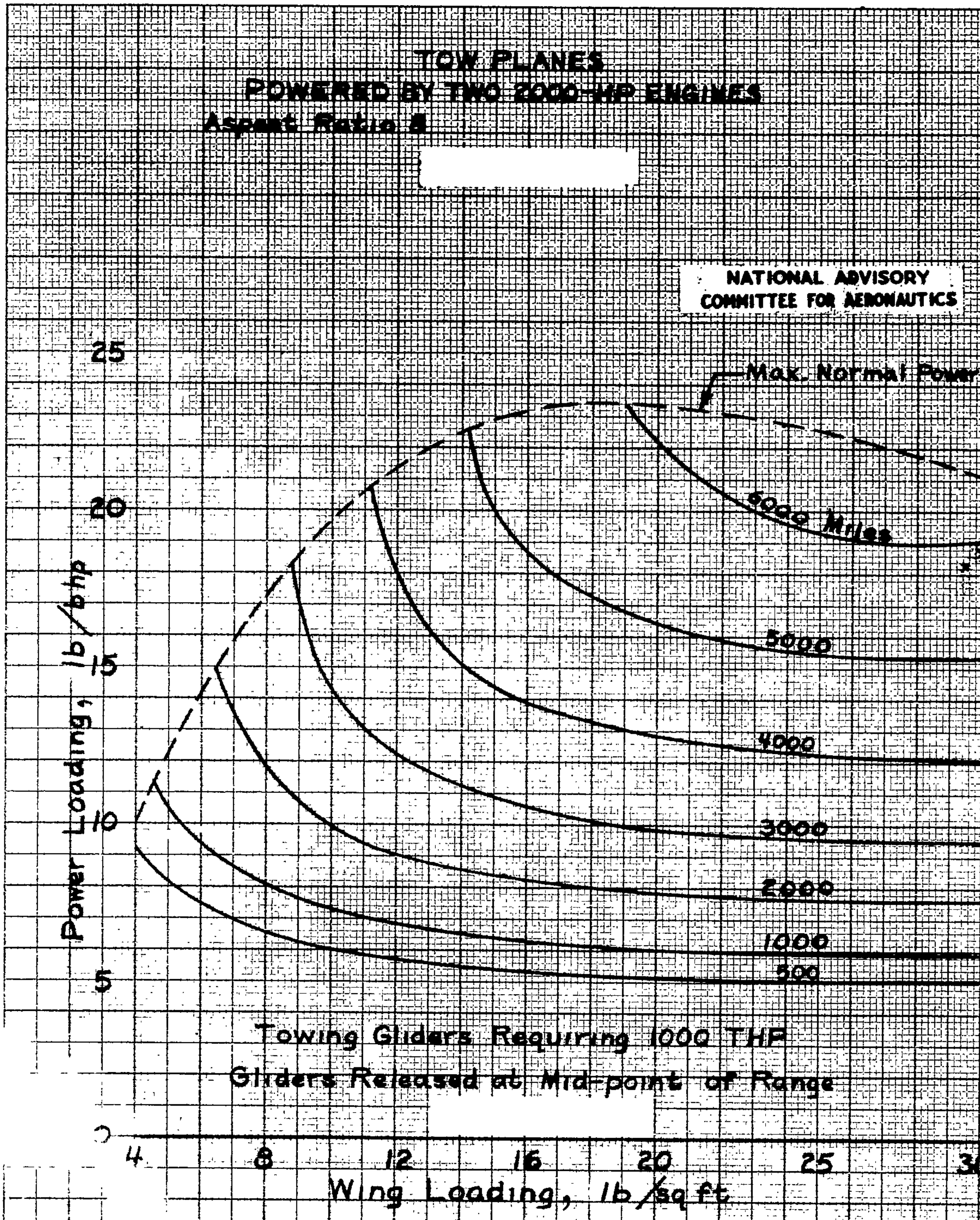

FIGURE 19 (c) RANGE AT 120 MPH

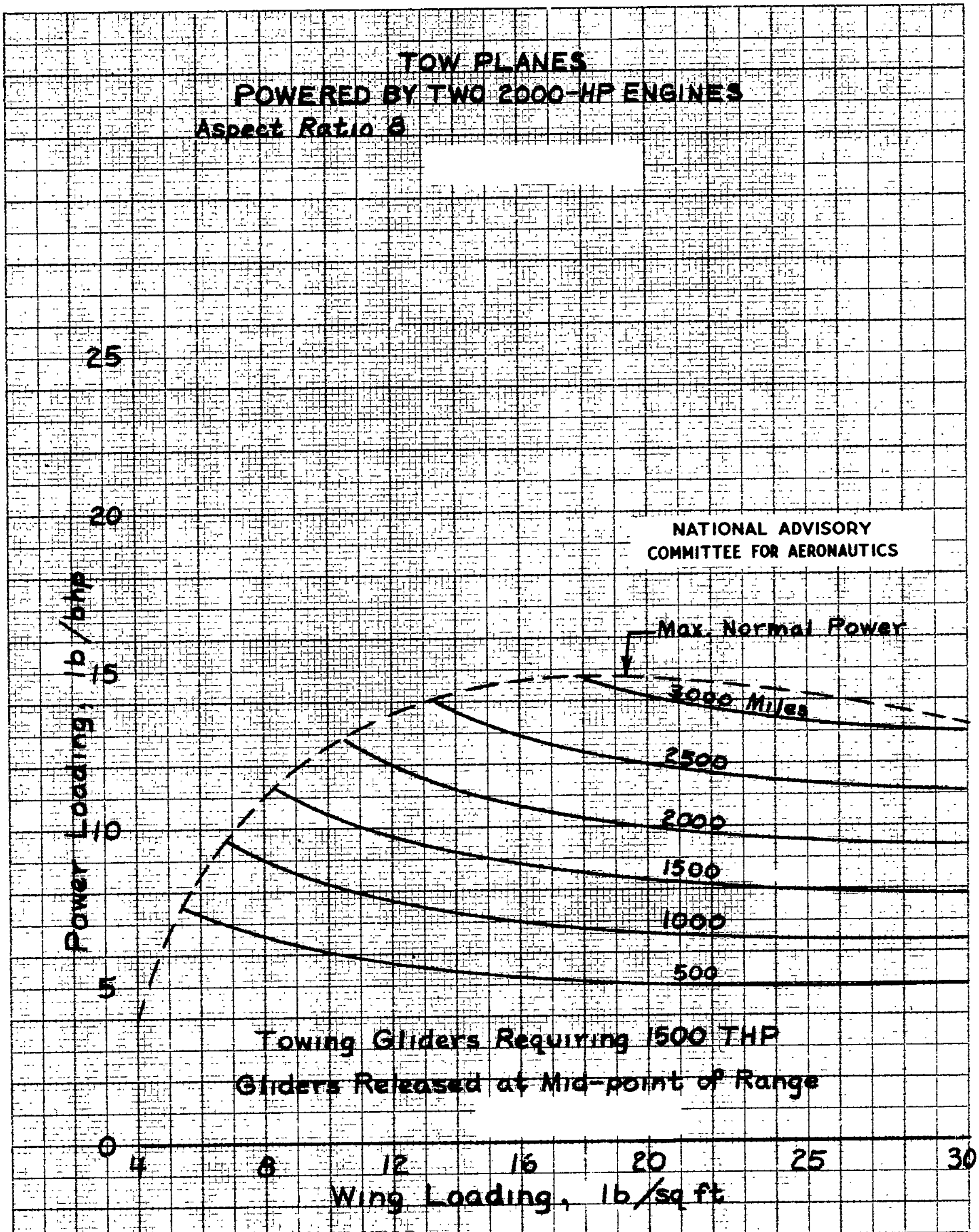

FIGURE 19 (d) RANGE AT 120 MPH

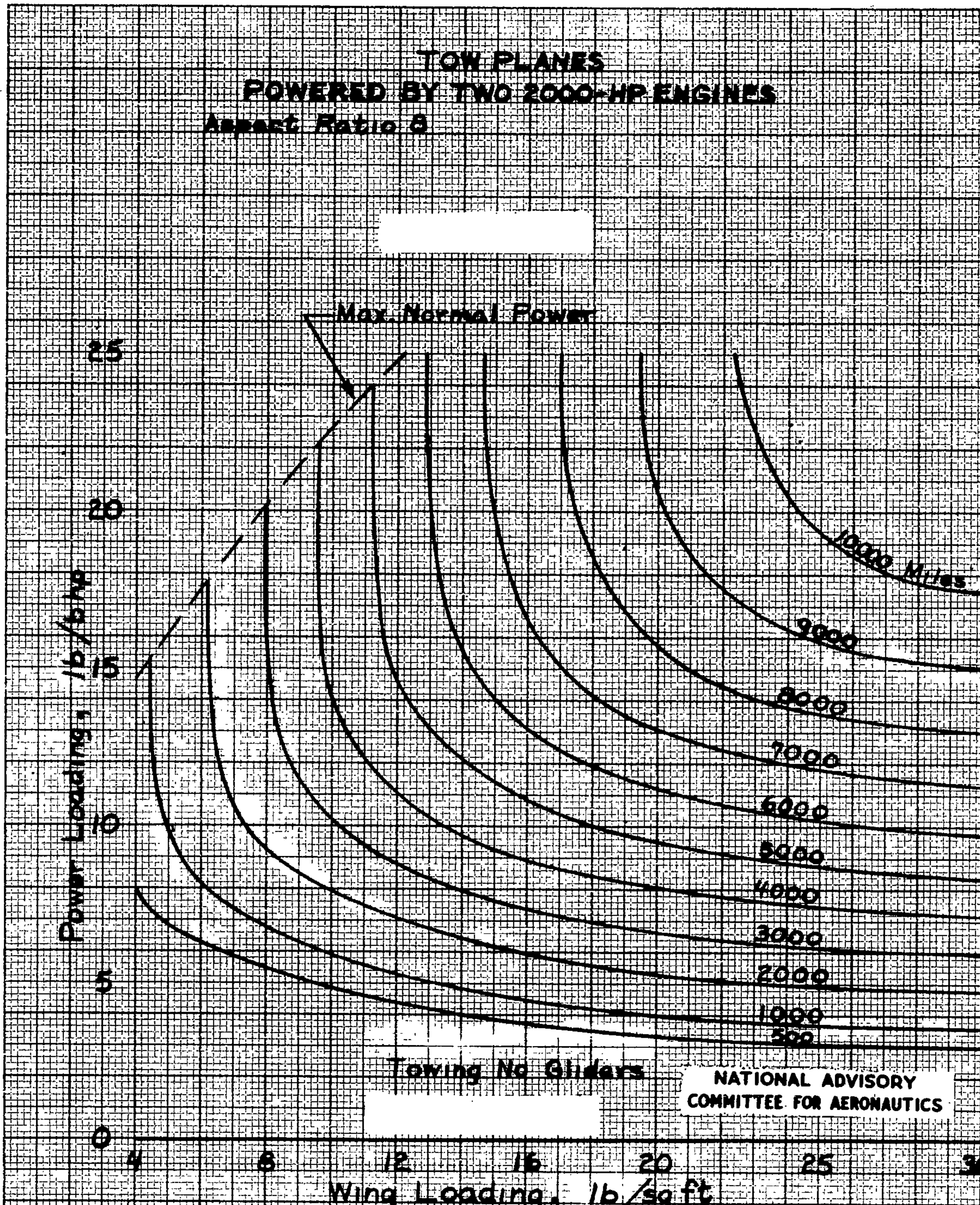

FIGURE 20(a) RANGE AT 140 MPH

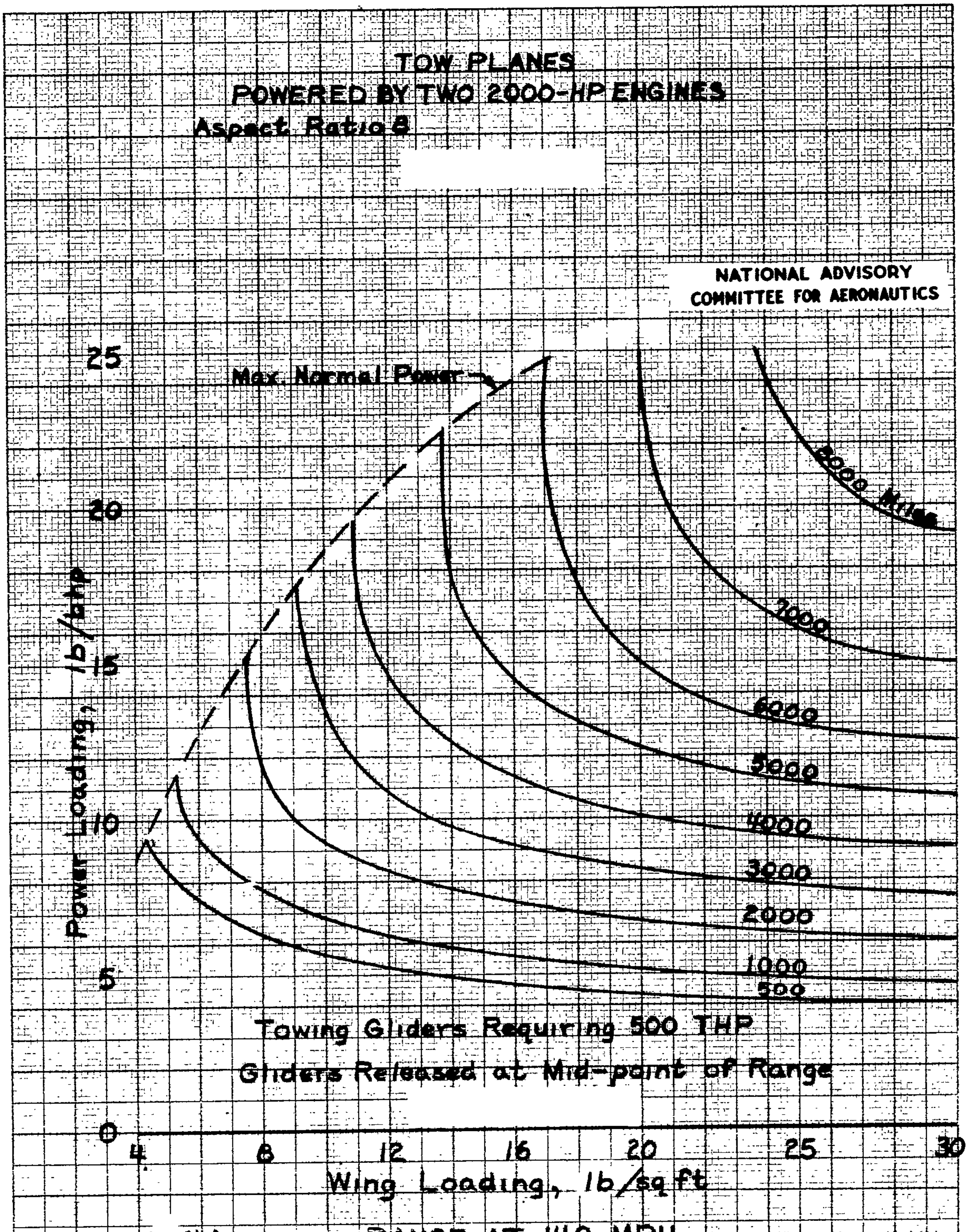

FIGURE 20(b) RANGE AT 140 MPH

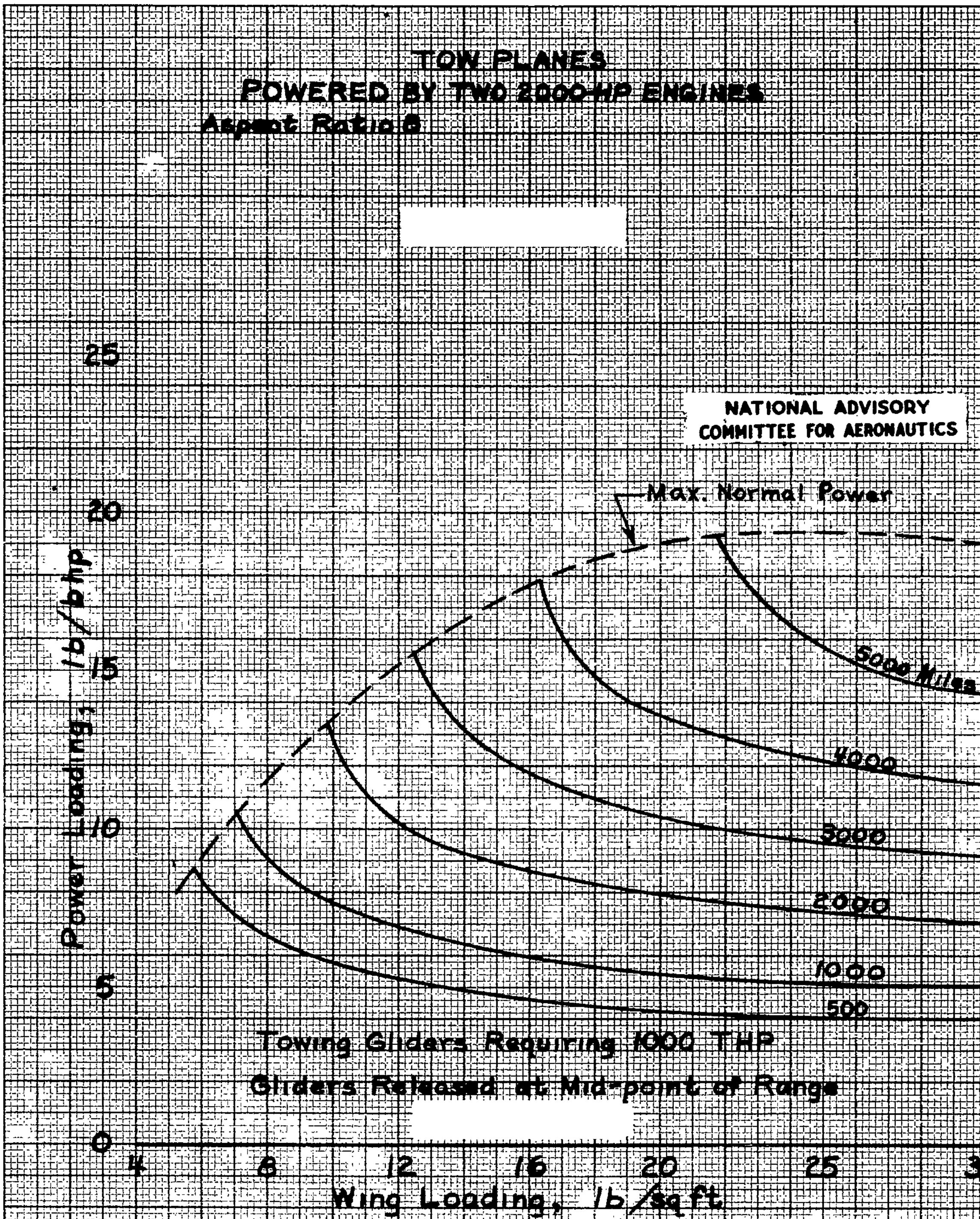

FIGURE 20(c) RANGE AT 140 MPH

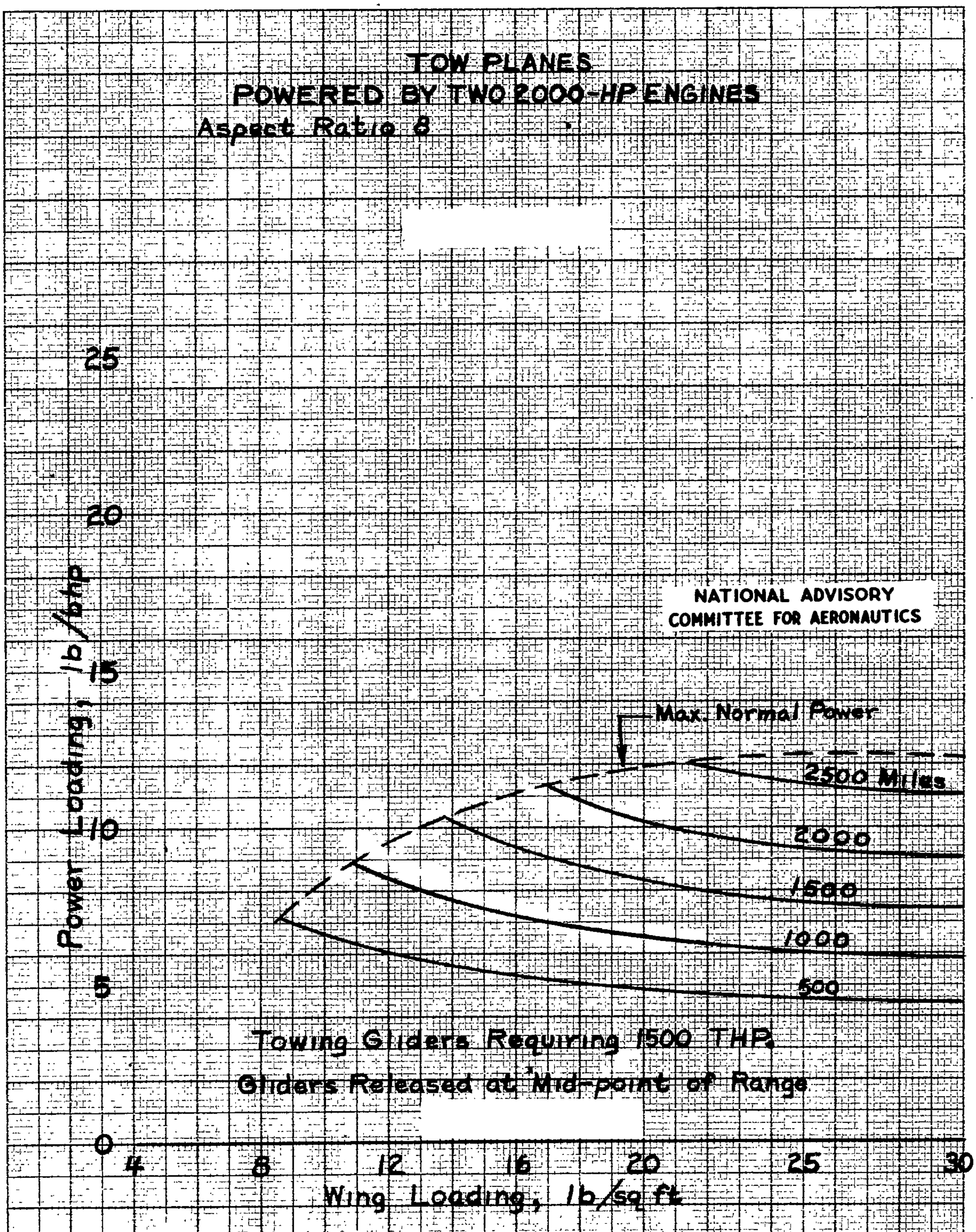

FIGURE 20(d) RANGE AT 140 MPH

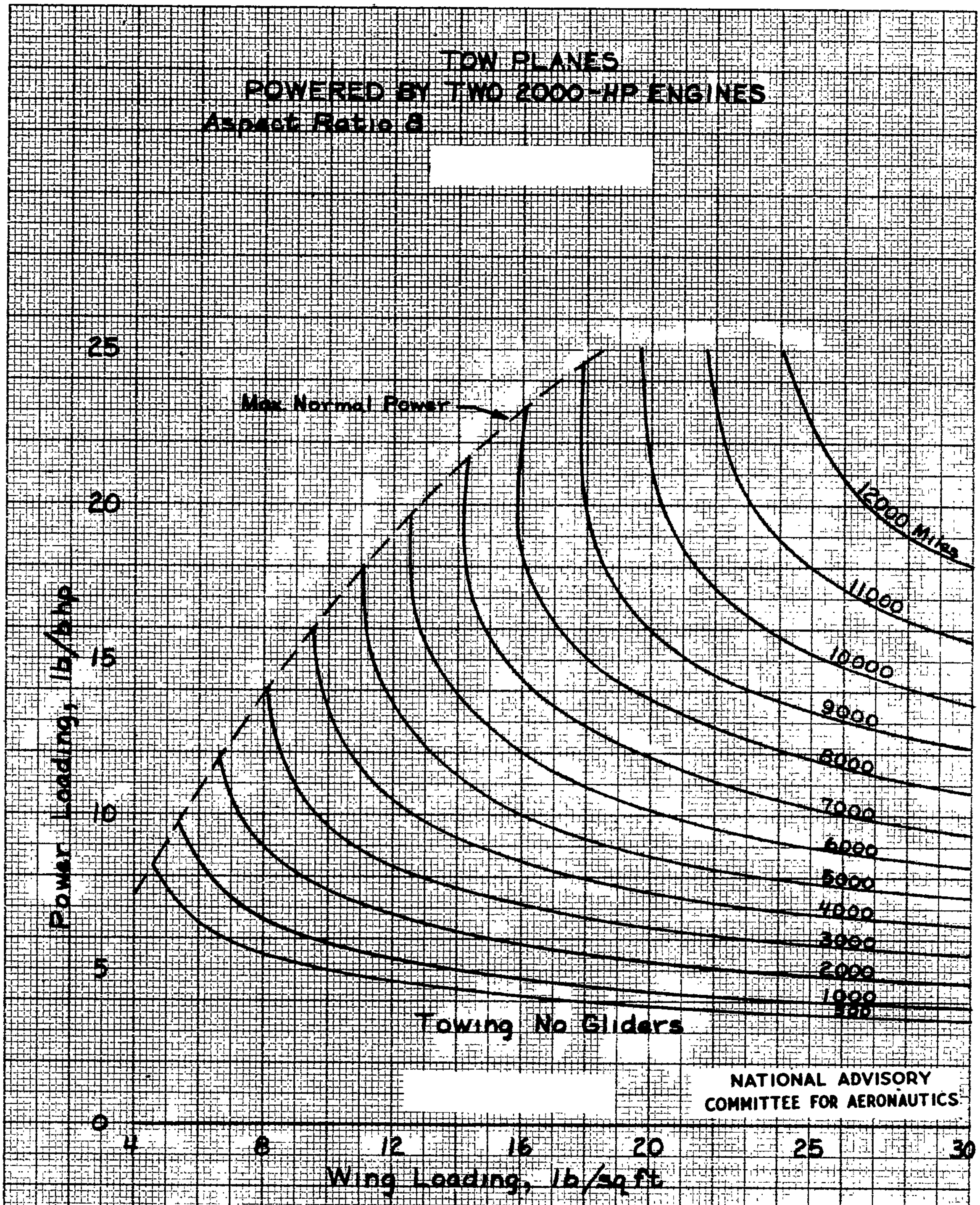

FIGURE 21(a) RANGE AT 160 MPH

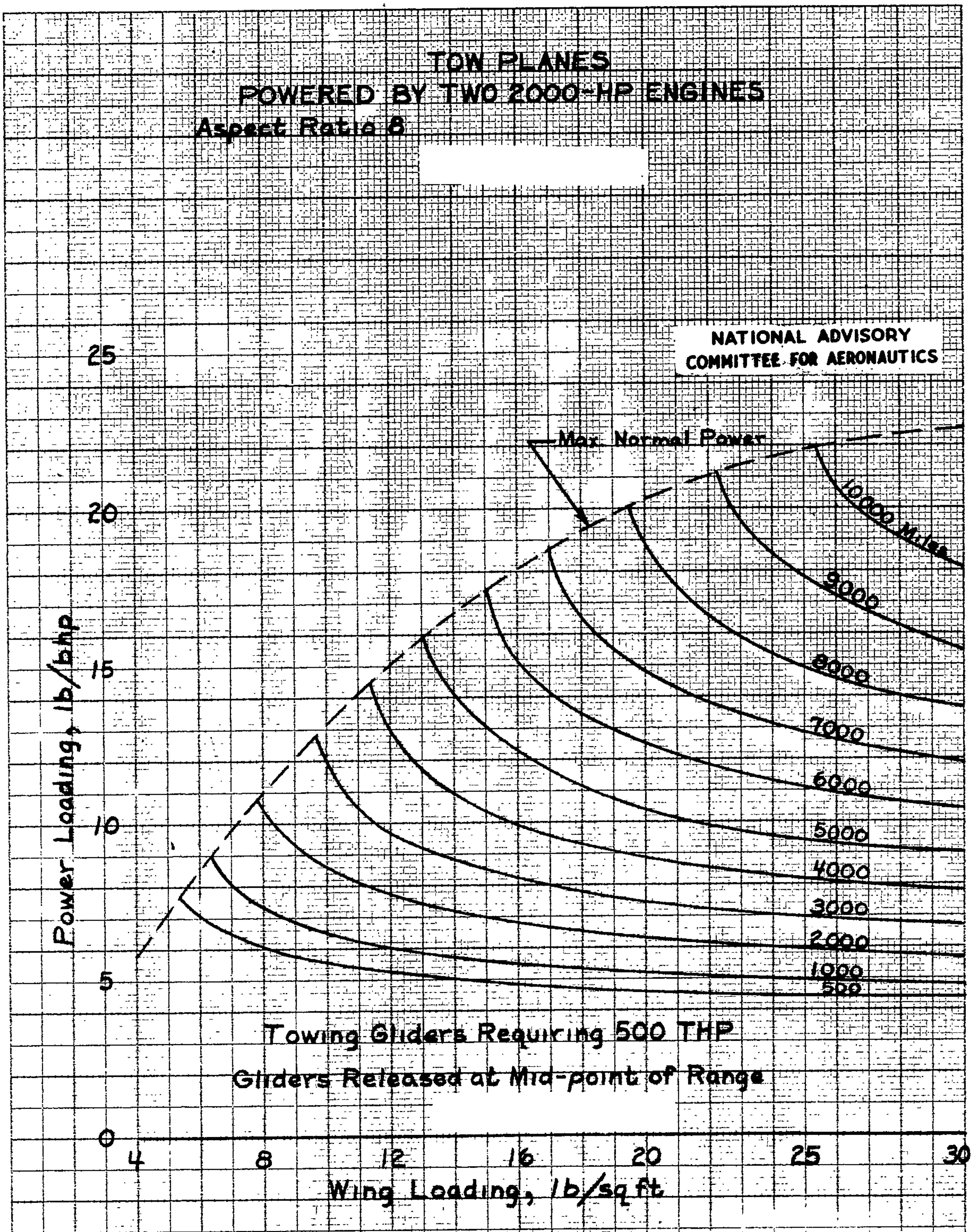

FIGURE 21(b) RANGE AT 160 MPH